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ORDINARY MEETING.

11 January, 1938.

SYDNEY BRYAN DONKIN, President, in the Chair.

The Scrutineers reported that the following had been duly elected as

Associate Members.

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ALFRED ARTHUR WOOD, B.Sc. (Eng.) (*Lond.*).
ERIC WOOD.

The following Paper was presented for discussion, and, on the motion of the President, the thanks of The Institution were accorded to the Author.

Paper No. 5159.

"Recent Engineering Developments in the General Post Office." †

By Sir George Lee, O.B.E., M.C.

TABLE OF CONTENTS.

	PAGE
Introduction	3
Problems of telephone transmission	5
The use of high-frequency alternating currents for telephony on wires	6
Radio-telephone communication: use of ultra-short waves	14
The speaking clock	16
Telegraphs	19
The Post Office tube railway	21
The general problem of postal sorting	23
Conclusion	30

Introduction.

As many of the new developments are electrical in character it is inevitable that the recording of progress most frequently takes place in the Institutions and scientific journals which specialize in electrical engineering. Civil engineering, however, is all-embracing in regard to engineering activities, and it is appropriate that the parent of all the engineering Institutions should, from time to time, have the opportunity of discussing developments in some of the more specialized forms of engineering.

It is proposed to describe briefly some of the more important developments in telephony and telegraphy, and in the conveyor- and machine-systems in postal work. All of these developments are dictated by the desire to perform certain operations with greater precision or with reduced costs. In the telephone field, however, the Post Office is faced with enormous growth due to the favourable public reaction to the new tariffs introduced in 1934 and subsequent years, and it is necessary to provide new methods of obtaining additional plant quickly. The annual increase in the number of telephones has changed from 73,000 per annum in 1931 to 250,000

† Correspondence on this Paper can be accepted until the 15th May, 1938.—Sec. Inst. C.E.

per annum in 1937, whilst the number of trunk calls in 1935 was 84 million and in 1937 it was 99 million. In telegraphy there is an increase of 45 per cent. in traffic due to the new tariffs, but this can be handled with the existing plant. The new methods under development in telegraphs are expected to produce far-reaching measures of economy and improvement of service. On the postal side, the growth of traffic is slower, and the efforts of the Post Office are devoted to mechanization of much of the work in sorting offices and to reduction of the physical effort of the staff employed there.

The technical developments of telecommunications have been very rapid since the War, and the rate of progress is becoming even more rapid. This is due to two factors: the first is that research on a large scale is being carried out in every important country in the world, and the knowledge gained in research is spread by the literature and by special international organizations set up for this purpose; the second factor is that telephony and radio, in particular, are growing rapidly in a commercial sense, and it needs a growing industry to take care of the financial effects of obsolescence. If dependence is placed merely upon the foresight exercised in the past in accumulating ample depreciation-reserves, there is a liability to restriction, in a stationary industry, in the application of the output of research.

One of the effects of research is to perform some function in a better and cheaper way. This gives the possibility of reducing tariffs, which in turn induces further growth. The increased growth allows for the absorption of more research, further tariff-reductions, and so on.

Much of modern research and development in the Post Office has emerged from the thermionic valve. Starting from 1871 when Cromwell Varley observed, in a cathode-ray tube, particles which could be deflected by a magnet, we have the discovery by Thomson of the electron theory, Fleming's diode valve, and finally in 1907, De Forest's three-electrode valve. The three-electrode valves of De Forest in America and of von Lieben and Reisz in Germany were the first valves to produce amplification and oscillation.

These valves were comparatively crude and unstable, and it has required a large amount of research work to produce the modern stable high-amplification valve; the best materials for the filament and other electrodes, the effects of temperature and potential-distribution, the production of hard vacuum, etc., have all been thoroughly explored, and the theory of design has been laid down.

Problems of Telephone Transmission.

In telephony comparatively weak currents, with energy of the order of 2 milliwatts, emerge from the microphone, and on a cable-circuit there are the ordinary ohmic and dielectric losses which, in a relatively short distance, attenuate the voice-currents down to a point at which they can no longer be heard in a telephone receiver. Amplifiers are, however, inserted at intervals on circuits worked at audio-frequencies to restore the voice-currents to a new high level.

One source of disturbance in line-telephony is that echoes are produced at points where there is a change of impedance, and particularly from the ends of the circuit. These echoes pass up and down the line, but cause no great trouble when the line is short. On long lines, however, they occur so long after the original cause that they disturb the speaker, and they also mix with succeeding syllables and so distort the speech. Most of the long lines of the Post Office are worked with two pairs, one used as a " go " and the other as a " return " circuit. Echo-suppressors have been devised which, in effect, allow only one of the pairs to be in action at a time, and thus the echoes are prevented from travelling to and fro. Modern design is also concerned with increasing the speed of transmission from about 20,000 miles per second, which is approximately the speed on existing cables loaded with inductances, to something of the order of 120,000 miles per second on carrier-cables. The deleterious effects of echoes will thus be reduced.

Cross-talk between circuits in a cable is a special source of difficulty in cables which are used with high-frequency currents, to which reference is made later. The pairs are twisted with different lays to reduce electromagnetic induction, and special arrangements are made to balance the capacity-effects between each pair and its neighbour. Interference from external circuits, including power circuits, is also a source of noise. Electrostatic shielding is employed in some cases to reduce cross-talk disturbances, as in the special music-circuits for the B.B.C., and the co-axial cable, described later, is effectively shielded electromagnetically as well as electrostatically. In general, however, all forms of induced noise set a limit to the distance apart at which amplifiers may be placed in order that the signal may never fall below a certain level with respect to the cross-talk and induced noises.

A further transmission difficulty which is found on the longest circuits is the alteration in phase-relationships of the different frequencies composing sound, which occurs as the signal is propagated over a long line. They do not all travel at the same speed.

It is fortunate that the ear is very accommodating both for echoes and phase-delay, and speeding up the velocity of propagation over the circuit is one means of coping with both these effects. Picture-transmission or television over wires or by radio will not, however, submit to either echoes or variable phase-delays on circuits on which telephony would be quite good.

The Use of High-Frequency Alternating Currents for Telephony on Wires.

Most of the difficulties which have just been recounted, except cross-talk, are overcome by the use of high frequencies in lieu of audio-frequencies, and it is now proposed to describe some of the technical advances which have taken place.

The last decade has witnessed a general advance in the use of high-frequency alternating currents on wires for telecommunication purposes. It might be described simply as the application of radio-frequencies to wires. Research work has been proceeding in Great Britain and in many other countries, the most striking advances being recorded in America, where the vast continental network of communications offers a wide field for this development.

The name "carrier" is employed to describe high-frequency telephony, because each frequency carries a separate telephone conversation. In addition to overcoming many transmission difficulties, the use of the carrier system enables many telephone conversations to be carried on a single telephone circuit. This is expected to lead to very considerable economies. The various frequencies are impressed on the sending end together and are separated out at the distant end by means of filters, and, passing through demodulators, become ordinary speech again. Several types of carrier development are in hand to suit the particular cables available or projected, varying from four carrier-channels on each four-wire telephone circuit for use on existing cables, to twelve-channel carrier on each four-wire circuit, where the "go" and "return" pairs can be placed in separate cables, and to the latest development, the co-axial cable, on which it is expected that four hundred carriers can be worked on each co-axial tube, the "go" and "return" tubes being separate but in the same cable.

These developments mean a very considerable economy of copper in line plant, against which must be set the cost of amplifiers and terminal apparatus with a very complex system of electrical filters to separate the various frequencies.

Electrical Filters.

Electrical filters for separating out alternating currents of different frequencies were described by Shepherd in Great Britain in 1912, and were extensively developed by Campbell and others in America, for use with amplifiers. An interesting recent development of the electrical filter is the use of piezo-electric quartz as one of the elements of the filter. The piezo-electric properties of quartz were discovered by the brothers Curie in 1880. They were investigated by the Curies and Langevin in France, and were developed for oscillation purposes by Cady in America and by Dye in Great Britain. A slice is cut out of a quartz crystal at appropriate angles to the axes, and is ground down to the required dimensions, when it will resonate to a particular frequency. The use of these crystals as part of an electrical filter system was suggested by Espenschied.[1] When an electric potential is applied to the two sides of the slice a mechanical strain is developed. If the electric potential is removed the mechanical strain is released and an oscillation is set up. When the frequency of the mechanical oscillation is the same as that of an applied electrical potential resonance occurs, and the slice of crystal presents properties equivalent to a combination of inductance and capacity. The electrical damping effect of quartz is very small, so that it is a very effective element in a filter.

Use of Carrier on Open-Wire Lines.

The use of carrier was first developed for open-wire lines by Ruhmer in Germany in 1909, and by Squier in America in 1910. The first important application for commercial purposes was described in 1921 by Colpitts and Blackwell.[2] At this date, and until recently, carrier was unsuitable for application on a large scale to underground cable-circuits, because as the attenuation is so great a large number of amplifiers, spaced fairly closely together, has to be used, and slight defects in amplification, which would cause no trouble when there are only a few amplifiers in tandem, become of great importance when the tandem amplification extends to, say, sixty amplifiers. With the introduction of the "negative feed-back" amplifier by Black,[3] of the Bell Telephone Laboratories, many of these defects have disappeared. The feed-back amplifier is very stable in its amplifying properties, the ampli-

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[1] American patent, No. 1,795,204/1931.

[2] E. K. Colpitts and B. Blackwell, "Carrier Current Telephony and Telegraphy." Trans. Am. Inst. E.E., vol. 40 (1921), p. 205.

[3] H. S. Black, "Stabilized Feed-back Amplifiers." *Electrical Engineering*, vol. 53 (1934), p. 114.

fication being relatively unaffected by wide changes in the supply-voltages. It also has relative freedom from the production of harmonics and from cross-modulation, the latter being a mixing of frequencies in such a way that the by-products cannot be conveniently separated. These are the defects which occur in an ordinary amplifier and are due to the amplification process not being completely linear; that is, the output is not simply proportional to the input. It remains to be seen to what extent feed-back amplifiers can be placed in tandem, as this depends upon the results attending the straightening of the amplification process.

Principles of Carrier Communication.

It may be desirable here to give a brief outline of the principles involved in carrier communication. Speech-currents are composed of a large number of components of frequencies varying between 75 cycles per second and 9,000 cycles per second. The frequencies which carry the intelligence, however, lie mainly in the middle band, those at the high and low ends contributing mainly to the naturalness of the speech, which is that factor by which the voice of the speaker is recognized. For economical reasons, in commercial telephony, the frequencies which carry the intelligence (namely, those between 300 and 2,700 cycles per second), are those which are chiefly transmitted, as this enables more conversations to be imposed on a given communication band-width. Suppose that a band-width of 60,000 cycles per second is available, and that it is decided to use the portion between 12,000 and 60,000 cycles per second for carrier working. A separating distance of 1,600 cycles between the bands is at present desirable to enable filter circuits to be designed conveniently, so that a single conversation demands a band-width of 2,400+1,600=4,000 cycles. This gives twelve channels in the band-width available. If the whole of the telephone band-width of approximately 9,000 cycles were passed, as would be done for music-circuits, only four or five circuits would be obtained in the same band-width.

The method of shifting the audio-frequencies to any point in the band-width available must now be considered. Taking the simplest type of case, in which a single voice-frequency d is employed to modulate in a valve a carrier of frequency f, in the output of the valve are found three frequencies $f-d$, f, and $f+d$. Means have been developed for eliminating f in this process, and filters will eliminate $f+d$, so that $f-d$ is then left. If f is 40,000 cycles per second and d is 1,000, the frequency becomes 39,000, and if d is now regarded as being composed of a group of frequencies surrounding 1,000 cycles per second, the group now appears at and

around 39,000 cycles per second. If each of the conversations is caused to modulate separate carriers of 16,000, 20,000, 24,000, 28,000 . . . cycles per second, the voice-currents will appear as bands of frequencies just below these nominal carrier-frequencies. The expression " nominal " is used because the carrier-frequencies are not transmitted along the line. All these separate groups of high frequencies are transmitted together along the circuit, passing through the amplifiers (or " repeaters " as they are called) together until they reach the demodulator at the distant end. The demodulator is very similar to the modulator and is followed by filters for separating out the different groups of frequencies, and it also introduces new carrier-frequencies to replace the missing carrier-frequencies. If a frequency f is added to the transmitted band $f-d$, the output of the demodulator valve becomes $f-(f-d)=d$. The remaining output-frequencies f and $f+(f-d)$ are suppressed or filtered out. The other transmitted frequencies are treated similarly. Thus the original audio-frequencies are restored at the receiving end.

Actually the process of modulation is more complicated than that described, and the frequencies may be stepped up to new positions in the spectrum by several stages. Further, in modern practice copper-oxide rectifiers take the place of valves in modulation and demodulation.

Economics of Carrier Working.

The economics of carrier working may be briefly summarized as follows :—

(1) The line circuit is shared by n conversations, depending upon the number of carrier-frequencies employed, leading to a considerable saving in copper.

(2) The intermediate amplifiers, instead of the normal practice of one at each repeater-point for each conversation, have the one amplifier shared by n conversations. This amplifier, however, has to be of a slightly larger capacity than in the normal case.

(3) A set-off against the two previous advantages is that the terminal apparatus contains valves and many filters, and is more complex.

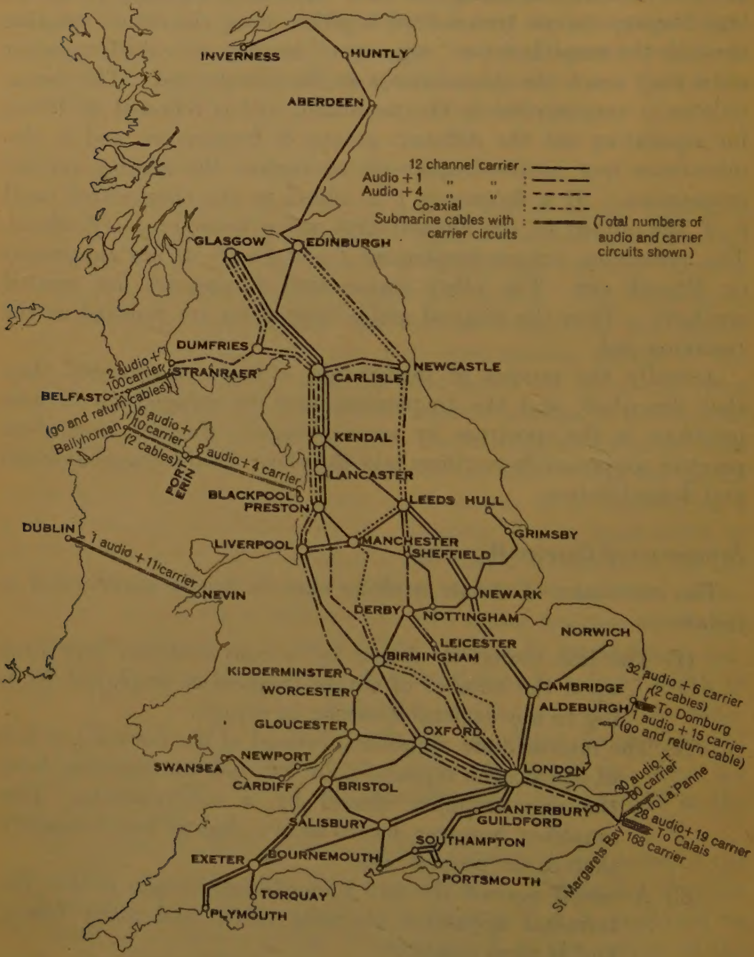
(4) The intermediate amplifiers have to be set more closely on account of the heavy attenuation with high-frequency working.

The net result is expected to be a considerable saving in copper and in the number of valves employed.

Carrier Working in Great Britain.

Fig. 1 is a map of Great Britain showing the programme of carrier cables at present in hand, including those which have already been completed.

Fig. 1.



Present Programme of Carrier and Co-axial Cables (including Existing Cables).

The twelve-channel carrier system, previously referred to, was installed by one of the cable and equipment contractors in Great Britain at the end of 1936, on two cables between Bristol and

Plymouth. This proving successful, a very large extension of the system to other routes has been planned, and is partly completed; it will probably serve as the principal system for new cables, with the addition of co-axial cables on the routes with heavier traffic.

Two nineteen-pair cables of 40-lb. conductors were employed between Bristol and Plymouth, one being used for "go" and the other for "return" circuits, the separation being necessary to prevent the large currents at the "go" end of a circuit disturbing by cross-talk the weak currents at the "return" ends of other circuits.

A frequency-band of 4 kilocycles was allowed for each channel, the carrier-frequencies employed being 16,000, 20,000, . . ., up to 60,000 cycles per second. The average spacing between the repeaters was 18 miles. As the maximum amplification of power which could be handled in repeaters of this type was of the order of one million, this spacing determined the highest carrier-frequency which could be employed, the attenuation of the highest carrier-frequency between repeaters being sufficiently below this value. If closer spacing of repeaters had been adopted and the conditions of cross-talk could have been satisfactorily handled, higher frequencies might have been possible and more channels per circuit might have been obtained, but this is a development which may come later when more experience has been gained. *Fig. 2* (p. 12) is a block diagram of the arrangement of apparatus at the terminal and repeater stations. The cables were of the ordinary twisted-pair type, but were very carefully balanced to reduce cross-talk effects. Future cables will probably be mainly of the "quad" type, which has a better space-factor than twin cables.

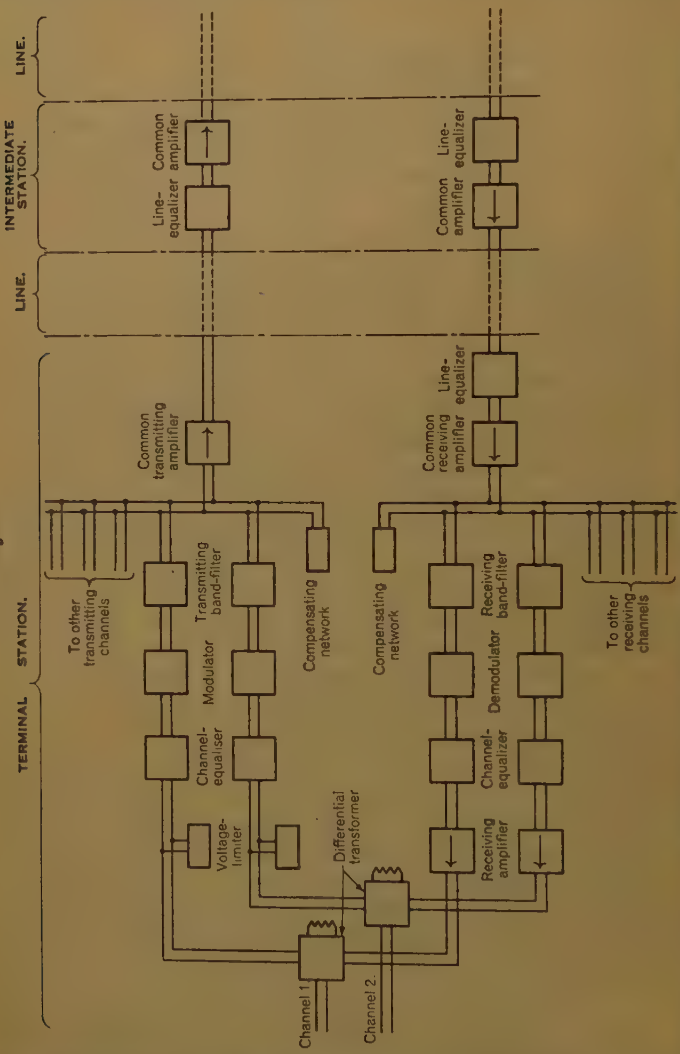
The co-axial cable development already referred to was undertaken to provide for a large growth in trunk telephone calls, and also on account of the possibility which this type of cable provides for transmitting television. It was evident that the number of radio wave-lengths available for television would be limited in number, and means for carrying television from central studios were therefore desirable. So far the telephone need has been the most urgent, and development work for the transmission of television is still in progress.

The first co-axial cables have been laid from London through Birmingham to Manchester, and are at present being extended to Newcastle. They will probably be carried into Scotland later. The unit structure in these cables is a tube formed of copper tapes with a central wire insulated from the outside cylinder. In the cables so far laid, four of these tubes are included, with worming pairs of

ordinary telephone type to fill up the interstices, the whole being covered with a lead sheath.

The tubes used are of two types; on the first between London

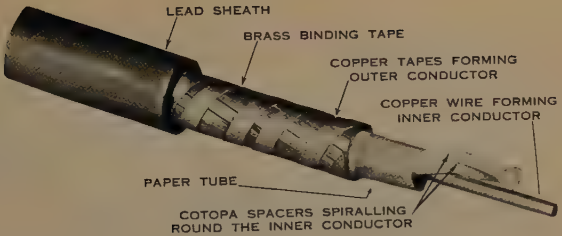
Fig. 2.



Block Diagram of Terminal and First Repeater Stations of Twelve-Channel Carrier-System.

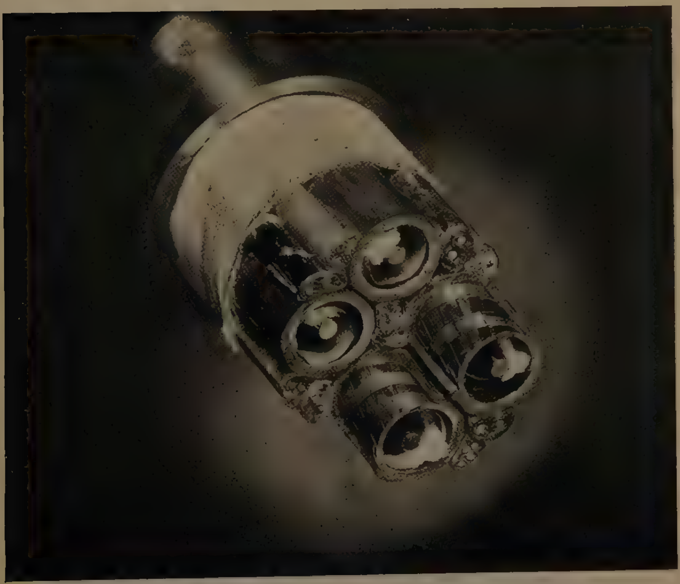
and Manchester the insulation of the central conductor is a two-ply cord of cotopa wound spirally around the wire. The external cylinder of copper tapes is covered with a thin lead sheath to bind the tapes together and to prevent buckling (*Fig. 3*). The construc-

Fig. 3.



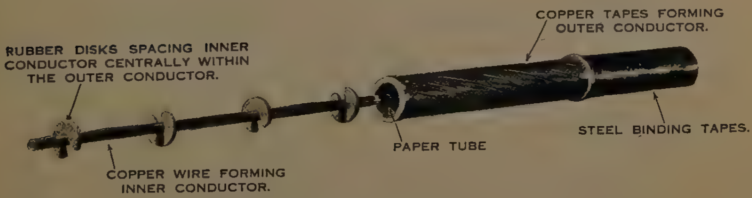
CO-AXIAL TUBE WITH COTOPA SPACING.

Fig. 4.



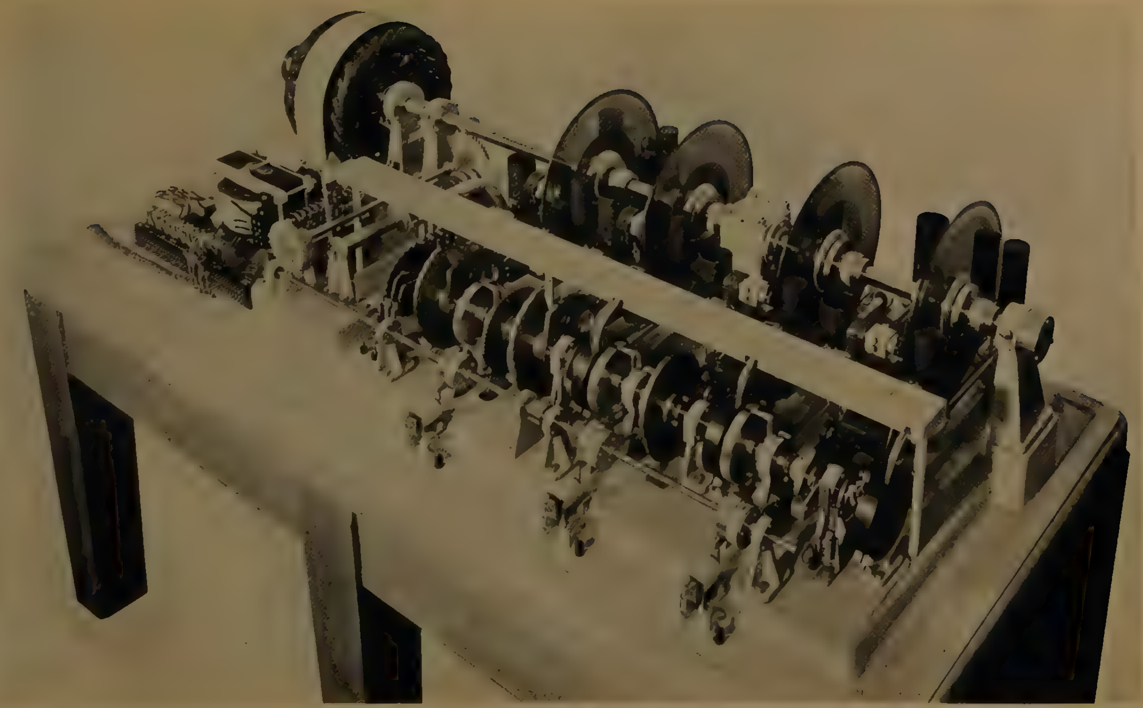
CO-AXIAL CABLE (LONDON—BIRMINGHAM) WITH COTOPA.

Fig. 5.



CO-AXIAL TUBE WITH DISK SPACING.

Fig. 6.



GENERAL VIEW OF SPEAKING CLOCK,

tion of the London–Birmingham section is as shown in *Fig. 4.* The thin lead sheath was replaced by a spiral lapping of iron tape in the Birmingham–Manchester section. In the second type of tube, employed between Manchester and Newcastle, the central conductor is insulated with rubber disks, and the external copper tapes are bound together with a spiral lapping of iron tape (*Fig. 5*). Both types are satisfactory from the mechanical standpoint of handling and bending the cable.

Design of Apparatus.

The design of the repeaters is such that they will handle an amplification of the same order as that employed on the twelve-channel system, and the average repeater-spacing was therefore fixed at 7 miles in order to keep the attenuation of the cable between repeater-stations to below this value. The screening effects of the co-axial structure are much better at high than at low frequencies, so that a range of frequencies at the low end will not be used. The range between 500,000 and 2,100,000 cycles is provided for by the repeater-spacing, and this is expected to carry 400 telephone conversations or one television channel. For telephony one tube is used as " go " and the other as " return," but for television the tubes will carry one television channel each.

This is a very interesting example of the demands on circuit provision made by the transmission of pictures. In order that the beams of light which constitute a television picture can be portrayed accurately and quickly, a band-width of 1,600,000 cycles is necessary at the present time, compared with a band-width of 2,400 cycles for commercial telephony, and with 9,000 cycles for music-circuits. It is possible that there will be a demand for more detail in a television picture, and the band-width necessary will increase at the same time.

It is impracticable to modulate the carrier-frequencies directly by the speech-channels in the case of these high frequencies, and three step-up processes of modulation are used. The first stage of modulation, using 5-kilocycle spacing, locates the speech-bands between 60 and 100 kilocycles, thus forming eight channels. It is expected that further work will enable the channel spacing to be reduced to 4 kilocycles. Crystal filters are used in this process to enable the high selectivity necessary to be attained. The groups of eight channels are used to modulate carrier-frequencies which locate these groups between 300 and 500 kilocycles, thus forming a super-group of forty channels. These super-groups are translated into the appropriate position between 0·5 and 2·1 megacycles by a further modulation.

As in the twelve-channel case, the actual carrier-frequencies are not transmitted but are re-introduced at the distant end. Actually, a highly-constant pilot frequency is transmitted over the line and all the carrier-frequencies are derived from it by processes of frequency-division and multiplication.

The repeaters have to handle the whole of the 400 conversations together, but as the peaks of speech do not occur at the same time in all the conversations the demand for power can be met by a pentode valve with a maximum anode-dissipation of 10 watts at 250 volts. The possibility of transmitting channels numbered in hundreds, through a single output-valve, without cross-modulation, is one of the most important economies of wide-band carrier operation. Only a few of the repeater-stations have staff in continuous attendance; at the others spare valves can be switched in and attention given later.

Radio-Telephone Communication: Use of Ultra-Short Waves.

The earliest experiments in radio-communication were made on very short waves below 10 metres in length, and recently there has been a return to this band of waves for commercial purposes. Waves shorter than about 7 or 8 metres in length are too short normally to be reflected by ionization in the upper atmosphere, and their service range is therefore restricted. It has sometimes been stated that these ultra-short waves are limited to optical paths, but this is not strictly true, and it is possible under favourable terminal conditions to use them for reliable communication for distances appreciably greater than the strictly optical distance.

An example of commercial communication within the optical range is the radio-telephone system across the North Channel between Scotland and Northern Ireland. The stations are situated at Portpatrick and Ballygomartin respectively, the latter location being about 4 miles to the north-west of Belfast. The Portpatrick site is about 250 feet above sea-level, while the Ballygomartin site is some 800 feet above sea-level. The distance between the two sites is approximately 36 miles, so that the path is entirely optical.

An initial installation consisted of a six-circuit system developed by the Post Office, consisting of six transmitters and six super-regenerative receivers at each end, involving twelve separate wave-lengths. Directive antennæ are used both for transmission and for reception, and the power-output of each transmitter to the antenna is approximately 5 watts. This system was brought into use in December, 1934, as part of the normal trunk service between

England and Northern Ireland, and it has been in continuous commercial operation since that date. It has recently been augmented by a further installation developed by one of the British manufacturers, in which a single carrier-wave of relatively high power is modulated by nine sub-carrier frequencies, each of which in turn is modulated by speech-currents. The frequency of the sub-carriers ranges from 150 to 300 kilocycles per second. The main carrier-frequencies used are 76,500 and 83,100 kilocycles per second (3·92 and 3·62 metres wave-length) in the west-to-east and east-to-west directions respectively.

The transmitters are of the crystal-controlled type and the final stage has a carrier output-power of about 50 watts. The receivers are of the superheterodyne type, consisting of a high-frequency amplifier followed by a demodulator which extracts the nine modulated sub-carrier frequencies. These sub-carrier frequencies are amplified and demodulated in the usual manner to restore the speech. The beating-oscillator supply for the first demodulator is also crystal-controlled to minimize the risk of frequency-drift. Directional aerials of the rhombic type are used for transmission and reception in one direction, and inverted-V aerials are used for transmission and reception in the opposite direction.

As an example of a service working over a non-optical distance, the radio-telephone service between England and Guernsey may be cited. Before designing the installation a number of tests were carried out between Guernsey and points in the south of England to determine the requirements for satisfactory service, and later a low-powered equipment was established near Shaftesbury for extended trials. The distance was approximately 105 miles and the heights above sea-level of the stations at Shaftesbury and Guernsey were about 400 feet and 270 feet respectively. The total optical range was thus about 45 miles, so that the working distance was $2\frac{1}{3}$ times the optical distance.

Using a transmitter of about 5 watts carrier-output and a simple type of super-regenerative receiver with a highly-directive antenna at each end, it was found that quite satisfactory service could be given during the summer and early autumn, but that in late autumn and winter the signal-strength gradually decreased until the received energy was only about one-thousandth of that received during the summer. As a result it was decided to shorten the distance by placing the English station at Chaldon, near Lulworth, Dorset. This brought the distance down to 85 miles, and as the Chaldon station was 500 feet above sea-level the working range was now 1·73 times the optical distance.

Two transmitters were installed at each station, each with an

output of 250 watts carrier-power, and the frequencies used are 35,220 and 54,300 kilocycles per second (8·517 and 5·524 metres wave-length) at Chaldon and 37,380 and 59,680 kilocycles per second (8·025 and 5·027 metres) at Guernsey. Crystal-control is provided, the crystal-frequencies being one-quarter of the final frequency with two frequency-doubling stages prior to the power-amplifiers. The receivers are of the superheterodyne type using an intermediate frequency of 3 megacycles per second, and automatic gain-control is fitted to counteract any fading.

The equipment is capable of transmitting modulation-frequencies from 100 to 10,000 cycles per second. As normally worked, each transmitter is modulated by two bands of speech-frequencies, one in the audio-range from 100 to 3,200 cycles per second, and the other from 6,400 to 9,600 cycles per second, so that with the two transmitters and two receivers at each end four telephone conversations can be carried on simultaneously.

The scheme has the advantage that should a high-quality music-circuit be required at any time, the carrier equipment can be cut out of circuit and the full band-width of the transmitter and receiver used for a single channel.

The aerials used are carried on self-supporting wooden towers 90 feet high, and are of the Koomans or pine-tree type, vertical radiators being associated with one channel and horizontal radiators being associated with the other channel at each end. The horizontal arrays are mounted above the vertical arrays, which ensures that the radiation from the horizontal system is emitted at a reasonably low angle.

The equipment has been in traffic service since the 8th May, 1936, and has given every satisfaction.

The Speaking Clock.

One of the by-products of the research on the telephone side is the provision of a time service which is continually available to telephone subscribers in London.[1] A subscriber, on dialling T-I-M if connected to an automatic exchange, or on asking for "Time" if connected to a manual exchange, hears the time announced every 10 seconds. Each announcement is followed by three audio-frequency "pips," the last of which indicates the exact time spoken within $\pm 0{\cdot}1$ second.

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[1] E. A. Speight and O. W. Gill, "The Post Office Speaking Clock." Journal Inst. E.E., vol. 80 (1937), p. 493.

The form of sound-record used is a set of four glass disks on which are photographically recorded the words and phrases required to build up the various announcements. *Fig. 6* (facing p. 13) is a photograph showing a general view of the disk arrangements.

One such disk carries records of the following phrases : outermost track, " At the third stroke " ; six inner tracks, " Precisely," " and ten seconds," . . ., " and fifty seconds." The second disk serves for the " hours " portion of the announcement and carries records of " it will be one," " it will be two," etc. These two disks each rotate at 30 revolutions per minute. The next disk serves for the " even minutes," and carries records of the even numbers from " two " to " fifty-eight," the place of zero minutes being taken by the words " o'clock." The last disk, the " odd-minutes " disk, carries records of the corresponding odd numbers from " one " to " fifty-nine," as well as a short record, lasting 0·1 second, of a 1,000-cycle note. The three " pips " are obtained by reproducing this note three times in succession. The last two disks each rotate at 60 revolutions per minute.

The individual speech-records are concentric circular sound-tracks of the " variable area " type, and are reproduced in the same way as the sound-tracks on talking films. A fine bright line of light is projected on to the track by means of a special lamp and a system of lenses, and the light transmitted falls on to a photo-cell. By this means a varying current is produced in the circuit containing the photo-cell, and, when amplified and fed to a telephone receiver, reproduces the original phrase.

A small shutter normally blocks the path of each beam of light from the optical system to the disk. One at a time the shutters are opened by electromagnets which are energized in the right sequence by the operation of contacts in the mechanism. In this way a word or phrase is reproduced from each disk in turn, to build up a typical announcement, such as : " At the third stroke it will be ten, twenty-five and twenty seconds—pip—pip—pip."

The one recording of " At the third stroke " and of the " pips " serves for every announcement, and fixed optical systems are therefore used to reproduce these. As the announcement is changed, one or more of the other optical systems must, however, move in order to reproduce different sound-tracks. Four of the six optical units are therefore mounted on carriages which run on transverse guides below the disk-shafts. The carriages are moved by means of steel cams mounted on three camshafts carrying ratchet-wheels. When it is necessary to move a carriage the appropriate cam is rotated through an angle equal to the angular separation of consecutive teeth on the corresponding ratchet-wheel. The wheel

itself is moved by means of a pawl carried on a swinging arm, which in turn is operated by means of an eccentric and connecting rod. The required precision of movement is obtained by forming the sheave of the eccentric as an integral part of an electromagnetic clutch, which is rotated through exactly one revolution at the appropriate moment. In every case the movement of the carriages is accomplished during the silent interval between the third " pip " of one announcement and the beginning of the next.

The whole of the mechanism is driven by a single motor, controlled as follows. Mounted on the bottom of a seconds-beating free pendulum is a photographic transparency on which a fine line of light is projected. The shape of the transparent and opaque areas is such that as the pendulum swings the amount of light transmitted and falling on to a photo-cell varies sinusoidally at the rate of 4 cycles per second. An alternating current at 4 cycles per second flows in the photo-cell circuit and, after amplification, is applied to stabilize the frequency generated by a three-phase 4-cycle oscillator. The output of the latter is again amplified, and is used to drive the motor, which is a three-phase machine with an eight-pole rotor, and therefore rotates at 60 revolutions per minute. A direct drive is used to the shaft carrying the " minutes " disks, and a 2-to-1 reduction gear is interposed between this shaft and that which carries the " hours " and " seconds " disks.

The circuit of the pendulum photo-cell amplifier is so arranged that any departure from normal amplitude of swing is detected, and an appropriate driving impulse is applied to restore normal conditions without the necessity for any form of contact operated by the pendulum. In this way the speed of the driving motor is controlled within very narrow limits. To avoid accumulated errors, however, the clock is automatically checked every hour against a signal transmitted from Greenwich observatory. If the time announced is more than $\frac{1}{20}$ second in error an automatic magnetic correction is applied to the pendulum whereby the clock is brought to true time.

In order to avoid unnecessary interruptions to the service, the installation comprises two clocks, one of which is in service and the other is running but is not speaking. If any fault appears on the working clock, such as faulty speech or an excessive time-error, the service is automatically transferred to the stand-by clock.

The service is distributed to subscribers from 100 special relay-sets located at " tandem " automatic exchange, and that number of subscribers can make simultaneous calls.

The service was inaugurated by the Astronomer Royal at 4.30 p.m. on the 24th July, 1936. Before 10.00 a.m. on the following day 37,000

calls had been made, and during the following week nearly 400,000 were made. Thereafter the weekly rate of calling fell first to 200,000, and then rose steadily to over 300,000. During the first year of service over 13,000,000 calls were made. Special occasions, such as the change from "winter" to "summer" time or *vice-versa*, or Armistice day, raise the weekly rate by from 15,000 to 20,000 calls, but an equal or slightly greater fall occurs at holiday periods.

Telegraphs.

There has been a quiet but far-reaching evolution in telegraphic methods during the past decade, the objects of which are to simplify operating and to reduce costs.

In the early part of the period there was the introduction of the teleprinter, a type-writing instrument, in lieu of the Morse and Baudot systems. The more heavily-worked Morse lines were converted to teleprinter working, and there are now a thousand such circuits. The lightly-loaded Morse and A.B.C. circuits were converted to telephone operation. Very much higher speeds of operation are possible with the teleprinter than with the previous Morse methods.

At the same time all the telegraph offices were remodelled to provide conveyor-belts along the tables and between tables and the circulation-points, to facilitate the transfer of telegrams from point to point inside the offices. Some difficult problems were met with in the design of these conveyor-belts to carry flimsy telegraph forms along horizontal and vertical runs without jamming or being stopped at the various turning-points. The effect of this ample provision of conveyors has been a shortening of the transit time inside the offices.

The next phase of development in telegraph working was the introduction of alternating current on lines in lieu of the former direct-current methods. Considerable ingenuity had been displayed in the past in duplexing and multiplexing with direct current, but the application of alternating currents enabled telephone methods, including filters and amplifiers, to be used, and gave up to eighteen telegraph channels on each telephone circuit. The eighteen channels used are the odd multiples of 60 cycles from 420 to 2,460 cycles per second. These are generated by a multi-frequency machine which is controlled in speed to a constancy of $\pm 0{\cdot}25$ per cent. Ten eighteen-channel systems can be fed from one machine. The system is known as "voice-frequency working" because all the frequencies used are in the normal speech-range and can be passed over the ordinary telephone circuits. The reliability of trans-

mission is much improved because the valve amplifier used on telephone circuits delivers a constant output in a more reliable fashion than the relay which is its counterpart on a direct-current circuit.

The teleprinter has to " key " the alternating current, in lieu of a direct current, and the current at the receiving end of the line, after being filtered from its seventeen fellows, has to be rectified in order to operate the relay or electromagnet associated with the printing side of the teleprinter.

The application of voice-frequency methods has reduced the cost of telegraph-line plant very considerably, and has enabled ample circuit provision to be made, where this facilitates operation. Further, so much telegraph-line plant has become redundant that it has been possible to hand over £2,000,000 worth of cables to be exploited for telephone working.

The next phase of telegraph development is still in the trial stage, but it is expected to lead to very far-reaching effects. The normal method of transmission of a telegram is as follows :—

Accepted from the public at a teleprinter office " A," it may be transmitted to a zone-centre office " B," where it is received on a teleprinter and passed over a conveyor-belt to another teleprinter on an outgoing circuit to zone-centre " C," where it is again taken down and re-transmitted to the distant reception office " D." The method under trial is the introduction of automatic (telephone) switching methods. With this system the outgoing office " A " will dial " D " direct with a code of from three to five digits. At " D " one or more teleprinters will be in operation ready to receive the message. When " D " has been seized by the automatic mechanism, its teleprinter will automatically transmit its call-sign to " A " to indicate that " A " may commence sending. At the end of the message " A " depresses a key known as the " Who are you " key, and " D " automatically again sends its call-sign, indicating that the line has been through to " D " and its teleprinter throughout the message. " A " then proceeds to other work, and at " D," where the teleprinter has so far performed all the operations of reception automatically, an operator attends and collects the tape for attachment to a telegraph form for subsequent delivery.

The switching apparatus employed is the same as that used in automatic telephony. In the final system there will be approximately thirty of these switching points located in different parts of the country.

The principal difficulties of the scheme will lie, on the operating side, in the choosing of the circulation and in the handling of errors, and, on the technical side, in the ample provision of line-channels

and switching plant to provide for peak loads. The system is at present being tried under traffic conditions to enable these problems to be studied.

The various methods of improvement developed had so far reduced operation costs by 1934 that the reduction of the minimum charge for a telegram to 6*d*. could be faced with equanimity. For years the Post Office had been confronted with a decline of traffic due to the competition from telephones and mails. The total number of inland telegrams fell from 55·7 millions in 1922 to 35·3 millions in 1934. The effect of the introduction of the cheaper telegram has been an increase on the 1934 figure of 44 per cent. This is very hopeful, and indicates that cost as well as convenience have their reactions in the use of telegrams by the public.

There were many technical difficulties which presented themselves for solution in the voice-frequency system. In general, the methods of telephone-transmission technique were applied to the solution of the purely telegraphic problem of the transmission of square-topped signals without distortion of shape.[1]

The Post Office Tube Railway.

In order to accelerate the carriage of mails through London, between certain railway termini and post offices, and to reduce, to some extent, the traffic congestion in the streets, it was decided that owing to the large quantity of letter and parcel traffic to be carried, this could only be dealt with satisfactorily by an automatic tube railway with electrically-operated trains.[2]

The railway runs from the Eastern District post office to Paddington station, calling at Liverpool Street station and at five sorting offices en route, and its total length is 6½ miles. The diameter of the running tunnel is 9 feet, and the line is of similar construction to the ordinary passenger tube railway, excepting that two tracks of 2-foot gauge are used. The largest station-tunnels have a diameter of 25 feet, the platforms being of the island type. The running tunnel is divided near the stations and is connected to them by 7-foot diameter tunnels. The track is arranged on the third-rail system with a central conductor-rail. Continuous track-circuiting with direct current at 24 volts is provided.

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[1] L. H. Harris, E. H. Jolley and F. O. Morrell, "Recent Developments in Telegraph Transmission and their Application to the British Telegraph Services." Journal Inst. E.E., vol. 80 (1937), p. 237.

[2] "The Post Office Tube Railway, London." *Engineering*, vol. cxxv (1928), pp. 92, 153, 214, 250, and 309.

Electricity is supplied for operating the traction and other equipment through three sub-stations, which convert the 6,600-volt alternating-current supply to direct current at 440 volts.

The rolling stock originally consisted of four-wheeled steel motor wagons, which were made up into driverless trains of two or three wagons. These were eventually replaced by bogie wagons having an overall length of 27 feet, and capable of carrying four containers, each train holding sixty letter or twenty parcel bags.

The electrical equipment of these wagons is very simple, consisting of two 22-h.p. series-wound motors connected in parallel. A resistance and brake solenoid are connected permanently in series with each motor, their impedance obviating an excessive rush of current when starting. This feature, which eliminates the necessity for any additional starting resistances, is unique to this railway and has operated very satisfactorily.

On approaching the station, the train enters a section on a rising gradient of 1 in 20, on which the conductor-rail is dead, and is stopped outside the station by the automatic brakes acting on the wagon-wheels. These brakes are held off by a solenoid which is always energized when current is passing through the motors, but are immediately applied by spring pressure when the train passes on to a dead section. After a short interval the conductor-rail is energized at 440 volts for a sufficiently long period to restart the train by means of an automatic camshaft gear installed in the station. The voltage is then reduced to 150, which corresponds to a speed of 8 miles per hour, and the train enters the station at that speed. If required to stop at a station platform, the train runs on to a section of the track adjacent to the platform which is dead, and is brought to rest by the application of the brakes. The length of the platform track-sections is determined by the maximum length of a train plus the distance necessary to bring a train to rest from a speed of 8 miles per hour.

For shunting purposes in the station areas, a 150-volt supply is provided by means of small motor–generators. Three powerful battery-locomotives controlled by a driver have been provided for maintenance and for emergency use, each being capable of drawing a fully-loaded train.

To enable the railway to be operated as efficiently and rapidly as possible, it is obviously desirable that the mail-bags be passed from ground level to the railway platforms with a minimum of handling. This is achieved by an extensive system of conveyors, elevators, spiral shoots and lifts. When lifts are used, the bags are loaded into the containers in the sorting offices and are wheeled to the lifts for the downward journey. At the railway-platform level, they are

wheeled from the lift to the wagons, where they are pushed into place over a movable ramp. The elevators, which are of the bucket type, are loaded by conveyors fed through hatches on the railway platforms.

Some particulars regarding the traffic dealt with by the railway will be of interest. During one week in January, 1937, a total of 118,462 letter bags and 74,145 parcel bags were carried. The annual car-mileage during 1936 was 1,791,290.

The General Problem of Postal Sorting.

The problem of improving the speed and accuracy of postal service at minimum cost, and of reducing congestion in existing sorting offices, has focused attention on to the possibilities of greater use of mechanical handling and sorting appliances.[1] Some idea of the traffic will be gained from the following figures, which give the number of items handled weekly at Mount Pleasant Inland Section :—

Letters :—		
	Average number	10,700,000
	Maximum ,, ...	14,500,000
Packets :—		
	Average number	2,400,000
	Maximum ,, ...	2,700,000
Parcels :—		
	Average number	400,000
	Maximum ,, ...	650,000

The growth in postal work during the past 32 years is shown in graphical form in *Fig.* 7 (p. 24), which indicates the total number of items posted in the country.

The figures do not tell the whole story, as in postal work there is a severe evening peak. Approximately 40 per cent. of the mail is dealt with between 4 p.m. and 8 p.m. In addition there are seasonal peaks, such as the Christmas traffic.

Mail may be broadly divided into three main classes, parcels, packets and letters, each with many sub-divisions such as C.O.D. parcels, registered letters, franked correspondence, etc., each calling for special treatment at some stage. In all classes the function of the Post Office is to collect the item from some point, transport it and deliver it, in its original form as far as possible, to the desired address. There is complete lack of uniformity about items sent through the Post Office in Great Britain, the only limit being the maximum size and weight of parcels. There is no lower limit.

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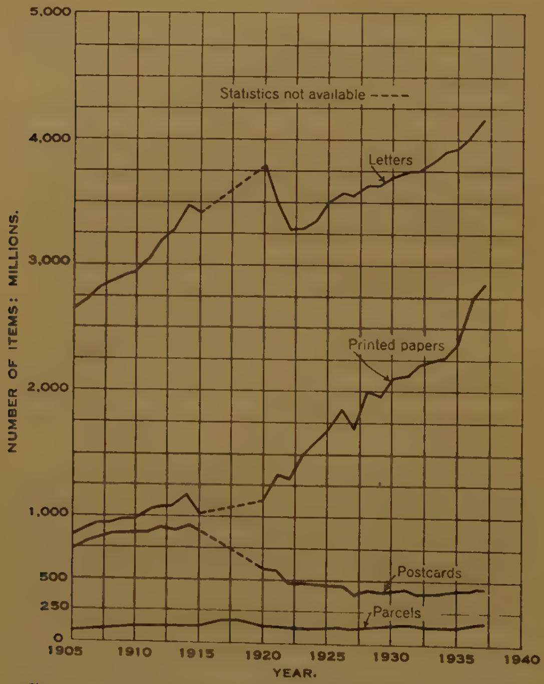
[1] F. Lane and J. Davidson, "Mechanical Aids in Sorting Offices." Post Office Green Paper No. 19.

Postal machinery must, therefore, be designed to handle items varying considerably in size, shape, and weight, even within the classes mentioned.

The sorting arrangements are similar for each class of mail. The outward mail (namely, mail posted in the district), is date-stamped and the postage-stamps are cancelled. The items are primary-sorted; letters into from thirty to forty-eight divisions, packets into twenty-four divisions, and parcels into from eight to twelve

Fig. 7.



GROWTH OF POSTAL TRAFFIC FROM 1905 TO 1937.

divisions, and then the items in each primary division are again sorted into divisions; in the case of some large offices a third sorting is necessary for part of the correspondence. After final sorting, the items are bagged ready for dispatch by railway or motor transport. In the case of inward mails (namely, mails received from other offices and towns for delivery in the district), the items have to be sorted into "postmen's walks" and in the necessary order for delivery in sequence.

The mechanization so far developed has mainly been in the

direction of speeding-up the transfer of mail between the points at which the various processes are performed (for example, between the unloading platform where bags are checked in and primary sortings, between primary-sorting and secondary-sorting positions, and so on), as there were obvious possibilities of economies and considerable reduction of congestion on the sorting-office floor. The trend of mechanization is now in the application of mechanical devices to the actual sorting processes.

Parcel work is segregated at all stages from letter and packet mail, and is dealt with in separate offices or in different parts of the same office, and this division will be convenient in briefly describing the installations.

Parcels Sorting.

The installation at the South-Eastern Parcels Office will be used to illustrate the line of development.

Bags of parcels from branch offices arrive at the office and are delivered to the loading platform, where, after checking, the bags are emptied through trap-doors in the platform on to an under-platform conveyor.[1]

The parcels are taken by rising conveyors to the top of a wooden glacis inside the office and are distributed along the glacis by manually-operated diverters on the glacis conveyor. This forms a convenient reservoir between the loading platform and the primary sorting, which prevents congestion on the platform and ensures that all parcels received in the office are ready for sorting at the earliest possible moment.

The sorters stand at the foot of the glacis, and the parcels are sorted into auxiliary conveyors, which feed on to main distribution-conveyors connecting direct with the secondary-sorting positions, where the parcels are delivered into baskets. At the secondary-sorting positions the parcels are manually sorted direct into bags hanging on drop-bag fittings. After bagging, labelling and checking, the bags are conveyed by outward conveyors running under the floor to the dispatching platform. *Fig. 8* (facing p. 26) indicates the general layout of the various conveyors and shoots.

Machine-Sorting of Parcels.

It will be gathered that mechanization has only been carried out so far as the actual conveyance of parcels between the various sorting stages is concerned, and that the sorting processes are very

[1] D. P. Gilbert, "Parcel Conveyors." Post Office Electrical Engineers' Journal, vol. 27 (1934), p. 179.

much as in manual sorting and handling schemes. Schemes such as have been described have been working successfully for a number of years, and have fully justified themselves. An experiment is, however, now being carried out with a parcel-sorting machine in which the actual sorting process is radically changed. The machine is being tried experimentally on the primary sorting of parcels with four sorting positions and ten selections.

The output of a sorter is primarily dependent upon the distance he has to convey a parcel from the glacis to the sorting box. This limits the number of divisions into which he can sort. In the new machine selective conveyors take the parcels from the primary-sorting position and deposit them in the appropriate secondary-sorting position.

The experimental scheme consists of a glacis serving the dual purpose of storage for parcels and a convenient means of feeding them to the sorters, and under the floor there are ten conveyors corresponding to the ten selections. These distribution-conveyors, by which parcels may be taken to the secondary-sorting positions, are spanned by tray-conveyors at right angles. Each sorter has sole use of one tray-conveyor immediately under his position, so that in the experimental machine there are four such conveyors, each comprising a series of trays arranged at the same pitch as the distribution-conveyor centres. The trays are fitted with opening bottoms.

The sorter is seated at the foot of the glacis and has in front of him a flap, connecting with a shoot terminating immediately over a tray-conveyor, and a set of push-buttons. The method of sorting is that the parcel is placed on the flap and the push-button corresponding to the selection required is depressed. The flap opens to allow the parcel to slide down the shoot. The operation of the push-button energizes the solenoid on a rotary switch at the selected distribution-conveyor, which in turn sets a trigger-releasing stud. The position of this stud on the rotary switch is such that it is not brought into operation until the required number of trays have passed; that is, until the tray containing the parcel for that particular selection is over the distribution-conveyor. The rotary switch is turned by a ratchet operated by the passing of successive trays, and it therefore counts the number of trays between the foot of the shoot at the sorting position and the distribution-conveyor for which the parcel is destined. The trigger on the switch releases a catch securing the two halves of the bottom of the tray and the bottom opens by gravity, thus discharging the parcel on to the distribution-conveyor.

The experimental machine is designed to run at a speed to permit

Fig. 8.

GLACIS AND PRIMARY-SORTING POSITIONS, SOUTH-EASTERN PARCELS OFFICE.

Fig. 9.

PACKET-SORTING FITTING, MOUNT PLEASANT.

5159.

Fig. 10.

"TRANSORMA" SORTING MACHINES AT BRIGHTON POST OFFICE.

sorting at the rate of thirty parcels per sorter per minute, as compared with the average speed of sorting into hoppers, which is approximately ten per sorter per minute. Another great advantage is that the sorter is enabled to sit while sorting, and the lifting and throwing of parcels is entirely eliminated. It is only necessary to turn the parcel the right way up to read the address and then to slide it on to the sorting flap. The risk of damage to parcels is also considerably reduced. It would appear that the number of selections is only limited by considerations of space occupied by the machine and distribution-conveyors. This is a definite departure from ordinary manual sorting, and although it is yet too early to say what the final development will be, the results of the experiment are distinctly promising.

Packet Sorting.

In Great Britain, packets and letters are largely posted into the same box, and there is no distinct line of demarcation between a packet and a letter. The first operation when bags of mixed packets and letters arrive at the sorting office is the separation of letters from packets. By letters must be understood those items which are thin enough to be dealt with by power-driven stamping machines. The segregation of packets and letters is carried out on facing-tables equipped with band conveyors. The lower part of the band runs towards the stamping machine end and is used for taking letters, which are faced by hand. The upper portion of the band takes the packets to the opposite end of the table.

Packets are delivered from the facing-table conveyors *via* shoots on to an under-floor conveyor, which delivers packets from all facing-table conveyors to a particular point in the sorting office. In the case of Mount Pleasant, packet-sorting has been mechanized to a large extent, and what follows is applicable to that office. The packets are delivered on to a packet-stamping table, where the postage stamps are cancelled by hand stamps. The distribution of packets along the stamping table is done by electrically-operated diverters. After stamping, the packets are dealt with at the packet-sorting fitting which is illustrated in *Fig. 9* (facing p. 26). This is a series of boxes approximately of 1-foot cube, comprising twenty-four divisions repeated nine times. There are three such fittings. Packets are sorted into the appropriate box according to the division required, and at predetermined intervals the bottoms of all the boxes for a particular division are opened automatically to deliver the packets on to a conveyor running under the fitting. There are four conveyors corresponding to the four rows of boxes, two conveyors running in one direction and two in the opposite direction.

These conveyors deliver on to distribution-conveyors by twin-band risers, and at the same time as the bottoms of the boxes are opened diverters are set across the distribution-conveyors to deliver packets to the correct division. The whole operation of opening the boxes and setting the diverters across the conveyors is fully automatic, the total cycle taking 3 minutes, so that every secondary division has a delivery of packets every 3 minutes. At the secondary-sorting position the packets are manually sorted into further divisions for final bagging and dispatch by under-floor conveyors to the dispatching platforms.

Letter-Sorting Machines.

A further stage in the mechanization of postal sorting is the introduction into Great Britain of the " Transorma " letter-sorting machine.[1] Two were ordered for trial at Brighton, and these were completed and brought into use in October, 1935. *Fig. 10* (facing p. 27) shows a general view of the machines.

The function of this machine is to permit all the letter-sorting in an office to be carried out at one operation instead of the usual method employing primary and secondary sorting, with the possibility, in a large office, of a third sorting for part of the correspondence. The number of divisions into which letters can be sorted at one operation by manual means is limited by the number of boxes which can be reached comfortably by the sorter. At Brighton, under the previous manual sorting systems, 40 per cent. of inward mail (that is, letters received for delivery in Brighton and district) and 37 per cent. of outward mail (that is, letters posted in Brighton and district) received a second sorting.

The machines at Brighton are identical and mounted on a platform which is continuous between the two. This arrangement permits either or both machines being used on either inward or outward sorting at the same time. Each machine provides for letters to be sorted into two hundred and fifty receptacles, the corresponding receptacles on the two machines being for letters going to the same destination. Each machine has five operator-positions, and the nominal speed of the machine is such as to permit a sorting rate of fifty letters per operator per minute, so that the complete installation is capable of dealing with 30,000 letters per hour.

The general principle of the machine is relatively simple. A series of carriers on an endless chain runs on a horizontal track ; at a

[1] W. T. Gemmell, " The Transorma Letter-Sorting Machine." Post Office Electrical Engineers' Journal, vol. 29 (1936), p. 16.

portion of their travel the carriers pass in front of the operators, each of whom has a keyboard and letter-dispatching mechanism. The operator inserts the letter in a slot, and keys a code number according to the destination of the letter. The letter is automatically transferred to an empty carrier, which is subsequently opened to discharge the letter into the receptacle corresponding to the number keyed. The use of a numerical code makes for a very simple keyboard and consequent ease and speed of operation, but it sets a limit to the number of divisions into which letters can be sorted at one operation, as there is a limit to the average operator's capacity for memorizing codes. This factor makes it impracticable under present conditions to introduce the machine in its present form in large offices, where as many as twelve hundred divisions might be required.

The box receptacles for the reception of letters from the carriers are built under the operating platform, and the two hundred and fifty receptacles per machine are built into two walls of one hundred and twenty-five receptacles each.

Letters from the stamp-cancelling machines are placed on trays and are conveyed by rising conveyors to the machine-platform; they are then taken by hand and are placed in a trough in front of each keyboard position. The letters are fed automatically up the trough so that the first letter is always convenient to the hand of the operator. The operator takes a letter and drops it into a slot and at the same time keys the number corresponding to the destination of the letter. The keys are depressed together and, by a selector-link mechanism, operate a series of cams, which in turn set selector rods on the carrier. The carriers, with the bottoms closed, run immediately under the slots in the keyboards. The chain of carriers is common to all five operators, so that each operator has access to every fifth carrier. The timing of the mechanism of the keyboard is synchronized with the passing of the carrier to which that particular operator has access. When this carrier is in position, the letter is discharged into it and at the same time the cams previously set by the depression of keys come into operation and set the selector bars. The carrier is swung to the correct inclination, there being ten possible inclinations, five on either side of the vertical, and when approximately over the correct row of receptacles, the bottom of the carrier is opened and the letter is discharged down the shoot leading to the correct receptacle. The discharge is by spring, so that the letter has a definite downward velocity and the actual point of discharge is somewhat in advance of the top of the shoot on account of the horizontal velocity imparted by the carrier.

After discharge of the letter, the carrier is brought back to the

vertical position, the bottom is closed, and selectors are returned to normal before again passing under the keyboard.

Since installation, the machines have given very little trouble mechanically. The machines handle approximately 170,000 letters per day during normal times, and during 4 days at Christmas, 1936, they handled approximately 1,300,000 letters. The principal difficulty which has been experienced is with the stacking of the letters in the receptacles. It is essential that in any letter-sorting machine the original facing of the letters be maintained, and it has not been found easy to prevent letters turning round, and in some cases turning over, when sorted at speed.

Conclusion.

The development work both on the telecommunication and postal sides at the present time is mainly in the direction of reducing operating costs by multiple use of circuits on the one hand, or by mechanization of the operations on the other. On the postal side the trend of development is in the direction of sorting machines, as distinct from mere conveyor arrangements.

It might be said that the work of the engineer is to create unemployment, by devising so many kinds of mechanization of what are at present manual operations. This, however, is a short-sighted view. The cheapening of communications by mechanization has so enlarged public demand that the staff has had to be increased very rapidly to supply the demand.

The Paper is accompanied by five sheets of diagrams and by twenty-one photographs, from some of which the Figures in the text and the two half-tone page-plates have been prepared.

Discussion.

The Author illustrated the developments described in his Paper The Author. y a number of lantern-slides, by demonstrations, and by the khibition of apparatus.

The President said that The Institution had been greatly The President. onoured by the fact that the President of the Institution of Electri-il Engineers had presented so interesting a Paper. The Paper as of great interest even to those who were not electrical engineers, id showed most clearly the great developments which had taken ace, particularly in regard to communication-circuits. The fact, ated by the Author in the beginning of his Paper, that the rate of crease in the number of telephone subscribers had been roughly ebled in 6 years, was most remarkable. To his mind the next most markable development was the transmission of 400 telephone talks ver one co-axial cable. The developments described were bound have led to very considerable economies; the economy in ommunication-circuits by the use of the carrier system, together ith the saving of £2,000,000 which had been effected by handing ver telegraph cables for telephone purposes, led to the hope that ven greater reductions in the cost of telephone-calls than had ecently been made would take place in the future.

Mr. Frank Gill remarked that the Paper contained a record of Mr. Gill. emarkable technical achievements in the building-up of a great rganization; those achievements had only been rendered possible y the men who had been responsible for precise measurements. He ould like to give two examples of conditions that were quite common ractice in telephone engineering, but were rather unusual else-here.

The first example concerned a telephone line, on which he would ssume that clear conversation could be maintained. That might e described in telephone units by saying that the line had a loss of bout 26 decibels. The unit used in telephone work was a shrinkage-ss, and as the scale used was logarithmic, 26 decibels would mean shrinkage to about one-four-hundredth. The energy emerging om the microphone was only about 2 milliwatts, which would erefore shrink to one-four-hundredth of that figure on the line; ere was therefore a loss in transit of about 99¾ per cent., which as a fantastic figure in power engineering, but was commonplace telephone work.

Mr. Gill's second example concerned the necessity for steadiness

Mr. Gill. in repeaters, to which the Author had referred. He would take th case of a long line, something over 2000 miles long, and woul assume that it had a loss of 1,000 decibels; that meant that th shrinkage would be 10^{100}, which was a tremendous figure. Th only way in which to deal with a line with a loss of that nature wa to counter that loss by a more or less equivalent gain; if fift repeaters were distributed throughout the line, each giving a gai of 20 decibels, the net loss at the end would be zero, and such line were quite practical. There were many circuits working in Grea Britain over 600 miles long with zero net loss. If, however, the gai of each of those repeaters varied by 1 per cent., he thought tha serious difficulties would arise, and if the figure was a little mor than 1 per cent. it would be quite certain that the line would b out of use. It was essential, therefore, that the repeaters should b stable.

As was stated in the Paper, the maximum frequency used ha been increased from 10,000 to 2,000,000 cycles per second, whils there was every indication that it would have to be still furthe increased. It was difficult in a few words to give any idea of th immense amount of work which had been necessary on the part o those engaged in devising new methods of precise measurement a those frequencies; such effects as attenuation, phase-distortion cross-talk and impedance had to be dealt with, besides all the usua fundamental electrical characteristics. The Author had characterize frequencies of up to 500,000 cycles per second as "the low end" that indicated how far the technique of high frequencies had bee developed.

Another point of importance was the manufacturing control Instruments had to be turned out in very large numbers, the had in themselves to be very accurate, and when they were connecte together they had to be such that they would not cause cumulativ trouble. A great deal of research and study had been put into th questions of how to control the operations in the factory and in th field, and to adjust the methods employed so as to be sure that i was possible to produce the required operating characteristics.

Lord Kelvin had observed "I often say that when you can measur what you are speaking about and express it in numbers you kno something about it; but when you cannot measure it, when yo cannot express it in numbers, your knowledge is of a meagre an unsatisfactory kind. It may be the beginning of knowledge, bu you have scarcely in your thoughts advanced to the stage of scienc whatever the matter may be." That seemed to be extraordinaril appropriate to the question which Mr. Gill was endeavouring t emphasize; namely, the tremendous importance of measuremen

and the great efforts which had been made in that direction in connexion with the developments described. Mr. Gill.

In the early days the telegraph had been considered to be of primary importance, and anything had been good enough for the telephone. The telephone had now become of prior importance, and had come to the aid of telegraphy by telephonic methods, such as voice-frequency working. In spite of that, however, telegraph traffic was apparently dwindling, whilst telephone traffic was expanding. He hoped that there were better days in store for the telegraph, but he confessed to being a little sceptical about its alleged dwindling. He knew that figures had been given, but there were to-day many busy firms who rented private telegraph lines and who sent their own messages by them. Were those private telegrams taken into account in the figures quoted by the Author, and was any coefficient applied to them to allow for long messages ? It would be interesting if the Author could give the approximate figure for the number of those private telegrams and state whether or not the revenue from them was included in the telegraph revenue.

There was one other small point which he would like to mention, purely as a matter of interest. The Author had referred to the action of engaging a distant teleprinter, of receiving an answer back, and of then knowing that it was possible to transmit the message to the other end. In the case of the machine used in Great Britain, the answer really did come from the machine which was about to receive the message ; but in the case of another type of machine, not used in Great Britain, the intimation came from the central office, and was in effect " I have told that machine to be ready, and you can take it that it is there " ; that, of course, was not a *bona fide* acknowledgement.

Even in a small country such as Great Britain where the telegraph had to compete with a very fast postal service—possibly the excellent postal service was the greatest competitor of the telegram—and had also to compete with the telephone, it still seemed surprising how difficult it was to develop a big telegraph business. In that connexion it was interesting to compare the amount of intelligence that it was possible to get over a line by telegraph and by telephone respectively ; on the telephone one hundred and fifty words a minute was as fast as anyone was likely to speak, whereas the telegraph operator could handle only about fifty words a minute, so that the telephone was three times as fast. One telephone-channel, however, required so wide a transmission-band that in the same width eighteen telegraph-channels could be accommodated, so that six times as much intelligence could be transmitted in a given time by the telegraph as by the telephone.

Col. Angwin.

Colonel A. S. ANGWIN remarked that one aspect of the recent developments described in the Paper which might be of particular interest to The Institution was the number of new materials which had contributed their part to those developments, whilst striking improvements had also been made in the mechanical and electrical characteristics of the materials used previously in the art of tele-communication.

An example referred to in the Paper was the piezo-electric quartz crystal. Piezo-electric quartz had been used for radio purposes for some time, but mainly to the extent of one or two crystals per transmitter for the frequencies which it was required to control. The development described in the Paper, where it was applied as one of the components in an electric filter, foreshadowed its employment on an entirely different scale of magnitude. The full equipment of two co-axial tubes in the cable between London and Birmingham, comprising four hundred telephone-circuits, would necessitate the employment of about twelve thousand crystals, each separately ground, which was equivalent to about ½ ton of raw quartz. Whilst piezo-electric quartz was to be found in several parts of the world, difficulties might arise in meeting the tremendously-augmented demand for it, and there seemed to be scope for a good deal of research and exploration to ensure that the demands could be adequately met.

Another example from the Paper was the use of magnetic cores for inductors. The earliest use of such cores in tele-communication was for loading coils. Early loading coils had been constructed with cores consisting of bundles of soft iron wire, but later iron dust had been used, and that had given place to nickel-iron alloys such as "Permalloy." Lately, for cores for filter-inductors, there had been a return to the use of iron dust, very finely-powdered iron being produced by either a mechanical or a chemical process (carbonyl iron). Progress in the design of loading-coils had been striking. The development of the improved type of magnetic core had reduced the size for a given performance to about one-eighth of the original bulk, and at the same time the stability of inductance had also been very greatly improved. The test which was usually applied to a loading coil was that of passing a current of 2 amperes through one winding and then determining what permanent change had been made in the inductive value. Instead of a change of 45 per cent., the change under similar conditions was now something less than 1 per cent. Nevertheless, many improvements could still be made in the type of core used for the inductors which were required, particularly in filter-circuits. A great deal of research in that direction in the past had been done in other countries, and

it was a matter which certainly required more attention in Great Britain. Col. Angwin

In connexion with cables, there was the question of an adequate protective sheath for the cable. The ordinary lead cable-sheath was subject to damage due to vibration, and even to fracture, but the greatest of all the troubles which it encountered was that due to electrolytic action or to chemical action when laid in the ground. So far, lead seemed to be the only possible metal to use as a protective covering. For land cables it was usual to employ almost pure lead, but where vibration was prevalent lead with a trace of antimony was used; for submarine cables lead with traces of antimony and cadmium was used. Where the cable was subject to severe electrolysis the difficulty was usually met by an additional covering of rubber-wax composition. He would suggest, however, that the ideal protective covering for the telephone cable had not yet been evolved; what was required was a covering which gave the required degree of flexibility and mechanical strength, and which was not subject to the prevailing difficulty with regard to electrolysis. A material which complied with that specification would go a long way towards preventing the cases of damage to cables which at present occurred, and would also help forward the objective, to which the President had referred, of still further cheapening the telephone service.

Of all the materials mentioned in the Paper, however, it was perhaps in the dielectrics that the most spectacular changes had been made. In the case of the co-axial cable referred to in the Paper, the use of cotopa, polystyrol, or vulcanized disks as the dielectric material made it possible to transmit the very high range of frequencies used without undue losses. Similarly, for submarine cables, materials such as "Paragutta" and "K-gutta" had been evolved which had the desirable characteristics of very low dielectric loss at high frequencies, and low dielectric constant. He did not think, however, that any telephone-engineer would be of opinion that the ideal dielectric had yet been made; he was sure that the Author would agree that the greatest importance should be accorded to the fundamental research which was being undertaken at many of the universities on the properties of dielectrics. As an example of a probable future development, he might mention the "hyper-frequency wave-guide system," where the dielectric itself was the medium for the transmission of high frequencies. It was possible to visualize the possibilities of a cylindrical tube of purely dielectric material, without any return conductor, for the transmission of frequencies of many millions of cycles per second; such developments were as yet hardly in the laboratory stage, but the discovery

Col. Angwin. of the ideal dielectric might give a practical solution of what seemed at present merely a tempting possibility.

With regard to mechanical aids to telegraphy, one very great difficulty which had arisen with regard to the conveyor-belts was the production of a belt-material which would convey the typical flimsy telegraph-message form without the phenomenon of electrification, which caused the message-form to stick to the belt and not to be delivered at the appropriate point. There again a very high standard of performance was absolutely essential. It was not possible to deal with percentages with regard to the loss of telegraph messages; the one telegraph message which was lost was always the most valuable and the most important. He did not think that up to the present any belt-material had been devised such that under no conditions of humidity or electrification of the atmosphere could a message fail to be delivered.

Dr. Morehouse. Dr. L. F. MOREHOUSE observed that it had been said that the field of electric communication was characterized by something unique in the whole field of industrial research; whilst it dealt with physical effects, such effects were neither the primary objective nor of primary interest. Private companies and administrations giving telephone service sold nothing of a physical character, as did organizations which were engaged in creating physical objects to be sold to a consumer; in tele-communications, and in fact in the wider field of communications generally, what was sold was the most intangible thing in the world—namely, the facility for men to transfer their thoughts from one place to another. In telephony the object was a system which would enable anyone anywhere to be put into instant and perfect communication with anyone else anywhere else in the world. That was the ideal, and it was probable that it would never be altogether attained; but very good progress was being made towards it.

The telephone service involved three important fields of research. The first field comprised the instruments at each end of the line, one of which converted the speech-waves in the air into electrical impulses which transmitted the waves to a distant point, and the other of which reconverted those electrical impulses into sound-waves which were substantial replicas of those which issued from the speaker's mouth. The Author had stated that the energy emerging from the microphone was about 2 milliwatts, but tests at the Bell laboratories in New York had shown that the average speech-power when talking in a conversational tone was only about 10 microwatts. Hence, in the microphone there was not only a translating device, but also a device which amplified the energy of the voice-wave about 200 times.

The second field of research in the telephone service comprised the channels over which the electric impulses were carried from one place to another; the channels had to transmit the electrical energy without impairing intelligibility. The telephone engineer then had, on the one hand, exactly the same problem as the power engineer (namely, that of efficiency), and on the other hand, the difficulty of so transmitting the energy as not substantially to impair the intricate and rapidly-varying speech-form in which the speech was delivered into the microphone. Dr. Morehouse.

The third major field concerned the means of inter-connecting the channels so as to provide quickly and economically for the random demands of those who wished to use the telephone service.

What apparatus was necessary in a telephone plant? In the London regional area there were over 1,100,000 telephones. Each contained a microphone, a receiver, a ringer, a condenser, a repeating coil, and in some cases a dial, all connected together in a special manner and all of them inter-related. Directly or indirectly, through the medium of special switching arrangements, each one of those telephones was connected by a pair of specially-insulated wires to what was called a switching-centre or exchange, of which there were more than two hundred and sixty in the London regional area. They varied in size and kind; some were arranged to deal with up to ten thousand lines, some were automatic in operation and some were manual. In the larger of those switching-centres there were thousands of relays, condensers, retardation-coils, response-coils, switches, storage-batteries and other apparatus too numerous to mention, all arranged in a perfectly-defined order and interconnected. To make possible the handling of telephone calls between telephones connected to different switching-centres, either in the same or in different areas, additional types of apparatus were required. The inter-exchange connecting circuits were of such size and characteristics as the circumstances required, ranging from the narrow-band type of cable to the broad-band type with which the Author had dealt. Not a single piece of that apparatus was independent of the rest; it was all inter-related. Each piece of apparatus, each cable, and even the ducts in which the cable was laid, had been the subject of considerable research and development.

Some idea of the load on the telephone plant in the London regional area might be appreciated when it was realized that in that area, 1,100,000 telephones originated annually more than 1,000,000,000 calls, whilst in Great Britain from 2,800,000 telephones over 2,000,000,000 telephone calls were made per annum. To the above load on the lines had to be added the immense amount of telegraph business handled by the Post Office, together with the

Dr. Morehouse. transmission of pictures and the teleprinter business to which the Author had referred. Moreover, television was developing. All those developments required apparatus and operating methods peculiar to themselves.

Not all of the development carried on by the Post Office was as spectacular as some of the things which the Author had described, but all of it was of importance for the economical development of the tele-communication and mail systems. In all that work the Author had to keep in mind the very important fact that in the art of tele-communication he was dealing at all times not only with the future but with an intricate past. Everything that he did had not only to be good in itself and to attain its objective, but in addition, no matter how good it might be, it could not be used at all if its introduction into an already complex existing entity would destroy a part of what had already been accomplished.

He had already remarked that the object of the telephone system was to enable anyone anywhere to communicate with anyone else anywhere else in the world. Enormous strides had already been made in that direction, more especially in the last decade. The first telephone communication, as was well-known, had taken place on October 9th, 1876, between Boston and Cambridgeport, Mass., over a line about 2 miles in length. In the world to-day there were more than 35,000,000 telephones, handling more than 43,000,000,000 conversations annually. That development had come about by keeping in mind the objective, by organized research, properly directed, and by sound engineering. Under the direction of the engineer-in-chief of the Post Office important contributions had been made and were being made in the whole of the art of communications, and pioneering work was being done in solving the problems which remained. In America telephone engineers were well aware of those contributions, and they congratulated the Author on what the Post Office had accomplished.

In conclusion, he would like to express his appreciation of the references in the Paper to the work of the great research laboratories of the Bell system, where several thousand engineers and scientists were constantly engaged in development and research, the objective of which was further improvement and extension of tele-communication services, and economies in operation.

Mr. Byng. Mr. E. S. Byng remarked that emphasis was laid in the Paper on the great importance of research; that had also been referred to by Dr. Morehouse. It had been truly said that research had three major objectives: how to do something hitherto impossible, how to do something in a better way, and how to do something at less cost. The benefits of research were not confined to plant;

Mr. Byng.

other departments of the Post Office, and many other big organizations, had found that operating methods could be modified so as to give new and better results at lower cost. Colonel Angwin had referred to research into materials, but research into market-conditions and many other researches were sadly neglected.

Ultra-short-wave development had been vigorously pursued during the last 5 or 6 years. Such waves had been used in earlier days, but their great possibilities had not then been realized. Early in 1931 telephone conversations had been conducted between Dover and Calais, a distance of about 24 miles, on a 16-centimetre wave-length, but there had been a certain amount of fading, although the range was well within the optical distance. It had been found that fading could be avoided by increasing the wave-length to about 3 metres. The remarks in the Paper on the operation of the ultra-short-wave link between England and Guernsey were of especial interest. It had been the general belief that the reliable range of communication on a wavelength of 5 to 8 metres was limited to that of optical visibility, but satisfactory commercial operation of that link had been obtained for a long period, covering summer and winter conditions, over a range of nearly twice the optical distance. Had any conclusions been reached as to why that was possible? Did waves follow the curvature of the earth after a certain distance? Could the same results have been accomplished over land?

Another ultra-short-wave circuit of some interest was that opened in 1935 between Barcelona and Majorca. In that case the range was about 93 miles, but the stations were located at such heights that the path was just within optical range. Excellent operation had been obtained, using a wavelength of about 5 metres with a 10-watt transmitter.

Other tests had recently been made; one had been reported from America in which communication had been maintained over a distance of 90 miles over land, though the path was obstructed by a mountain projecting more than 1,000 feet above the line of sight. In that case it had been necessary to use approximately 40 watts on wavelengths of 7·5 and 10 metres in order to secure reliable communication.

The Author referred to the recent inauguration of the first multi-channel ultra-short-wave radio-link between Scotland and Northern Ireland. That was a very interesting achievement, and the application of what might be called wide-band technique to commercial communication might be found to open the way to new methods giving marked improvement in the signal-to-noise ratio for a given power; engineers appeared indeed to have merely touched the fringe of a field of investigation with extremely wide and interesting possibilities.

Mr. Carrothers. Mr. C. G. CARROTHERS remarked that the Author had drawn special attention to the economy in copper which resulted from the use of multiple-frequency working, and it would be of interest to know whether in addition to economy there was any gain in serviceability, and whether the Post Office would prefer to provide a given service by expenditure on lines rather than by an equal expenditure on apparatus. That was an important matter in other branches of engineering, as for instance in power engineering, where it was often necessary to perform a large number of operations at a distance; it was then necessary to choose between methods involving the simplest possible terminal apparatus with a large number of separate pilot circuits, and methods involving complicated terminal apparatus with a limited number of pilots. Where the cost of the two methods was equal, it was customary in power engineering to choose the method which involved the simplest terminal apparatus, and perhaps the Author would say whether that was in line with what would be indicated by experience in telephone and telegraph engineering.

The Author had referred to the importance of the specialized branches of engineering being considered as matters of general interest. Many of the problems which power engineers were approaching for the first time had been already overcome by telephone and telegraph engineers, and it would be interesting to know whether the Author saw any way of co-ordinating the work of the special branches with that of the more general branches of engineering.

The Author. The AUTHOR, in reply, stated that he entirely agreed with what Mr. Gill had said as to the necessity for precise measurements. One of the most striking facts about the development of radio work after the War had been the lack of means for precise measurements. Prior to the War most radio transmission had been by means of spark but, with the coming of continuous-wave methods, there had also arisen the possibility of making precise measurements. It was no exaggeration to say that the wonderful developments which had taken place in radio since the War had been entirely due to the possibilities of measuring all the quantities involved and of putting the work on a sound engineering basis. In that sense carrier-telephony was indebted to the work which had been done on radio-telephony.

With regard to dwindling telegraph traffic, it was hoped that the new switching system to which reference was made in the Paper would mean a considerable reduction of the losses on the telegraphs; but the present position—and he was sure that Mr. Gill would be pleased to hear it—was that the Post Office regarded the telegraph traffic as part of the telephone service. The technical methods

ow employed on telegraphs were, in effect, telephone methods, nd the circuits used formed part of the normal telephone-system. The Author.
n many businesses there were items which it was possible to run t a loss because that loss was covered by other items. It was matter of convenience to the public, and on those grounds the ss on the telegraph service, which incidentally was being reduced onsiderably, was justified. The telegraph service was a national ervice of communication which was available everywhere in Great ritain to the poorest of the population, and in such conditions the uestion of a profit or a loss on that service did not determine hether it should or should not be given.

Mr. Gill had asked whether the telegraph services for private ires in the hands of different firms were included in the figures, nd the answer was that they were not. There were at the present me about 1,500 teleprinters on private wires in use, and they were ainly in the hands of firms sending a large number of telegrams; o information was available as to the number of telegrams actually ent. A good deal of that development was, however, not competitive with the telegraph service, but it formed a new convenience or large business firms. For example, between London and Liverpool there were sixty-three private telegraph circuits in use, but the ost Office had never had anything like that number in use between hose two towns, and the number of circuits used by the Post Office ad increased rather than decreased during the period of the development of the private-wire service.

Colonel Angwin, who was the principal expert who had been andling from the Post Office side the question of the carrier cables, ad made some interesting comments on the difficulties in obtaining upplies. Colonel Angwin's remarks on magnetic materials were of nterest, but he did not refer to the difficulty which had been experienced in obtaining samples of powdered iron of the right quality, s the fact whether the particles, which were very small indeed, were pherical or angular, made a difference in the results obtained. He ad also referred to dielectrics. Many new high-quality dielectrics vere being produced, Some of them, for example polystyrene, had power-factor at high frequencies of almost nil. Other dielectrics vere being produced with a very high dielectric constant. There was till room, however, for very considerable research in dielectrics to roduce the varied classes which were required for different purposes vith due regard to temperature-coefficient, constancy and economy. Ie had referred also to the belts used for conveying telegraph forms etween the different portions of telegraph offices. The problem f getting a belt which would not become electrified had not been olved, but Colonel Angwin himself had solved the difficulty tem-

The Author. porarily by an arrangement of photo-electric devices which di tinguished between the white of the telegraph form and the black the belt; if a telegram went round the pulley at the end of the bel run, the photo-electric cell immediately rang a bell.

Dr. Morehouse had referred to the research and other work do by the American Telephone and Telegraph Company, and th Author would like to acknowledge very freely the work done by tha company in America. It had a vast continent to serve and it too a very broad view of research. The result had been a very hig output of telephone research and development which had set a example to the whole world as to the way research could be co ducted and the certainty with which results might be obtained.

Mr. Byng had inquired about the fading on the ultra-short-wav circuit to Guernsey. There was fading on that circuit, but it could b handled by the volume-control fitted on the receiver. The answer t the question of why the circuit worked over twice the optical distanc was probably diffraction, but the knowledge on that subject was no complete. There had been several reports, both in Great Britain an in America, of the discovery of new layers below the "E" laye layers only some 10 to 12 kilometres above the earth. On the othe hand, the existence of such layers had quite recently been dispute and more work had to be done on the matter. If those layers di exist, they would account for many of the phenomena associate with ultra-short-wave transmission. It was, of course, also possib to work over land beyond the optical distance, as Mr. Byng ha pointed out, but the results in general were not so good.

Mr. Carrothers had inquired which system the Post Office woul prefer if the costs of wire and of the technical apparatus in the com plicated carrier systems were the same. The answer was tha simplicity was always to be preferred, and at present the carri system was only used over distances of such a length that the resul ing economies made it worth while to incur the complications whic arose. Mr. Carrothers had also asked whether some co-ordinatio was not possible between power engineers—presumably those co cerned with the transmission of instrument-readings and other i formation from one point to another on the power system—and tel communication engineers who had already solved a good many the problems which arose. The answer was that co-ordination di exist either directly between the power engineers and the Post Offic or through the manufacturers, but if anything further was require the Post Office would be very glad to assist.

*** The correspondence on the foregoing Paper will be published in the Inst tution Journal for October, 1938.—Sec. Inst. C.E.

Paper No. 5086.

"The Creep of Portland Blast-Furnace Cement Concrete.

By Allan Dawson Ross, Ph.D., B.Sc., Assoc. M. Inst. C.E.

(*Ordered by the Council to be published with written discussion.*)[1]

TABLE OF CONTENTS.

	PAGE
Introduction	43
Test-conditions	44
Apparatus	44
Calibration	45
Tests	46
Stresses induced by creep	50
Conclusion	51

Introduction.

Within the past few years reports of the work of research-workers have drawn the attention of engineers to the creep or time-deformation of concrete. Creep has been shown to take place over a period of several years with a magnitude of three or four times the initial elastic movement on loading. Consideration of the effects in reinforced-concrete members shows that large changes occur in the stress-distribution, particularly in the case of compression-steel, where high stresses are realized with a consequent reduction in the concrete-stress. Creep is also a vital factor in deflexion and in the development of shrinkage-stresses in reinforced or restrained members.

The effects of creep in structural mechanics are so vital that quantitative data for all classes of concrete become desirable. Information of this kind can only be obtained as a result of time experiments, with special apparatus, under carefully-controlled conditions, and so the amassing of reliable quantitative, as distinct

[1] Correspondence on this Paper can be accepted until the 15th May, 1938, and will be published in the Institution Journal for October, 1938.—Sec. Inst. C.E.

from qualitative, results, has been slow. The problem has been further complicated by all the variable factors inherent in concrete work. The water/cement ratio, grading, age at loading, humidity, surface/volume ratio, mineral character of the aggregate, and the class of cement all have marked effects on the magnitude of creep. It seems probable that some time must elapse before it will be possible to forecast with any degree of certainty the creep of any concrete under a given set of conditions. The results are given here of an attempt to supply further creep-data hitherto unreported. Much valuable work has already been done with Portland, rapid-hardening Portland, and aluminous cements, and the Author felt that a fourth class, namely Portland blast-furnace cement, merited an investigation which would give an indication of its behaviour under sustained stress.

Test-Conditions.

Throughout the tests carried out, the temperature was maintained at approximately 64° F. by thermostats and electric heating-elements. Apparatus for the control of humidity was not available, but wet- and dry-bulb thermometer readings were taken simultaneously with all strain-observations, thus enabling local variations in the curves of movement with time to be explained, and giving also an approximate mean relative humidity for the period of the test.

Apparatus.

A lever-apparatus constructed of rolled-steel sections (*Figs. 1*), was employed, the four springs being carefully calibrated before

Table I.—Details of Springs.

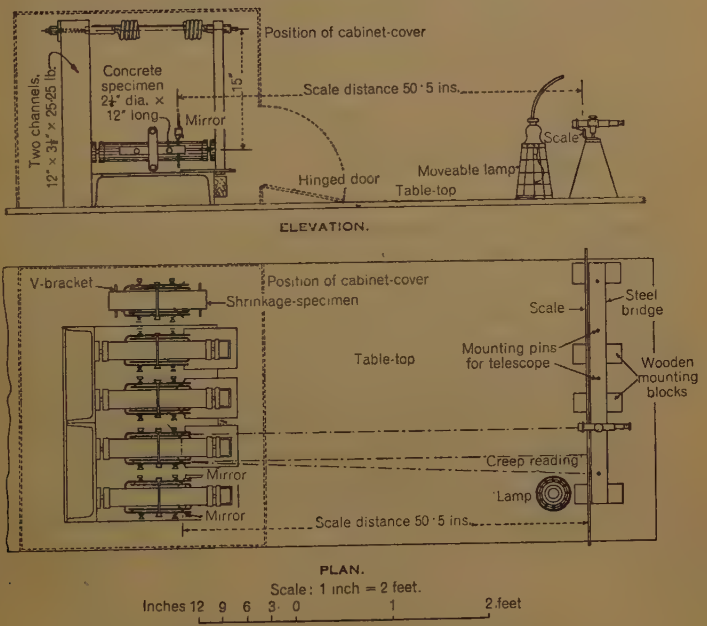
Mean diameter of coils: inches.	Spring load: lb.	Load on specimen: lb.
$2\frac{1}{8}$	227	1,589
$1\frac{31}{32}$	341	2,387
$1\frac{23}{32}$	454	3,178
$1\frac{21}{32}$	568	3,976

All springs are of $\frac{3}{8}$-inch diameter steel.

use (Table I). An unstressed specimen for observation of shrinkage was mounted, adjacent to the specimens being tested, in smooth

V-brackets which could offer no appreciable resistance to movement. Loads were applied through case-hardened platens and steel balls, and strain-measurements were made by means of roller-and-mirror extensometers, designed to suit the lay-out of the apparatus. In order to increase sensitivity and to eliminate errors due to rotary or translatory movement of the specimen as a whole, the two elements

Figs. 1.



of the extensometer were used conjointly. The line of sight entering the instrument was maintained directionally constant by making the vertical cross-hair of the telescope coincide with a hair-line in the right-hand mirror for each reading. In operation, the telescope was swung on its vertical mounting-pin until coincidence was obtained, was locked in that position, and then the scale, seen by double reflection at the two mirrors, was focused and the reading was taken.

Calibration.

With $\frac{1}{8}$-inch diameter rollers, and a distance from the mirrors to the scale of 50·5 inches, the scale divisions of $\frac{1}{60}$ inch corresponded

to 1×10^{-5} inch strain on an 8-inch gauge-length, or to $1{\cdot}25 \times 10^{-6}$ inch per inch. By interpolation of scale divisions, movements of $0{\cdot}62 \times 10^{-6}$ inch per inch could be recorded. The probable maximum errors in concrete-stress due to control of spring-deflexions and measurement of lever-distances amounted to 0·8 per cent. and 0·4 per cent. respectively. A single straight scale was employed instead of a segmental one for each specimen, introducing an error estimated at a maximum of 1 per cent. Normally the error was considerably less than this, and corrections were deemed unnecessary in view of the other experimental approximations.

TESTS.

Series I.—The first concrete tested was a 1 : 2 : 4 mix of Portland blast-furnace cement, river sand, and crushed whinstone; the mechanical analysis of aggregates gave the results shown in Table II. A relatively dry but nevertheless workable mix, with a water/cement ratio of 0·55 by weight, gave a cube strength of 3,735 lb. per square inch after 28 days' water-curing. Six specimens 2¼ inches in diameter and 12 inches long were prepared, two being controls for the measurement of shrinkage and elastic strain. The cylinders

TABLE II.—MECHANICAL ANALYSIS OF AGGREGATES.

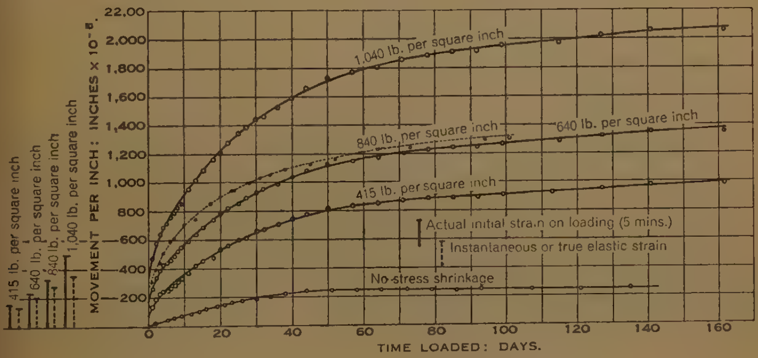
Sieve.	Percentage residue: Sand.	Percentage residue: Broken stone.
½-inch	0	0
⅜-inch	0	44·8
No. 4	0·5	80·8
,, 8	34·1	96·5
,, 18	79·1	98·8
,, 30	86·2	100·0
,, 50	95·4	—
,, 180	100·0	—

were cured in wet canvas for 2 days after removal from the moulds and were thereafter exposed to the air of the laboratory.

After 28 days, loads were applied and observation of movement was made every 1 or 2 days initially, and at longer intervals thereafter for a period of 162 days. An elastic test on the control specimen, with a low maximum stress of 302 lb. per square inch thrice repeated, gave a modulus of $3{\cdot}0 \times 10^{6}$ lb. per square inch, which enabled the creep occurring during the 5-minute period of loading to be computed. This quantity has been included in the

creep–time curves which are shown in *Fig. 2*. The specimen maintained at a stress of 840 lb. per square inch showed relatively less creep, and it is thought that, in spite of efforts to obtain uniformity, the consolidation in this cylinder was more perfect than in the others, which would lead to an earlier transference of the load to the aggregate with a consequent reduction in the rate of creep. Some confirmation of this is obtained in the shape of the curve, which indicates that the proportionality of creep to stress was good for the first few days, that is to say, before large changes in the internal stress-distribution had taken place. The remaining three curves, however, show that creep is approximately proportional to stress, and this is indicated clearly in *Fig. 3* (p. 48), which connects elastic strain plus creep with stress for various ages. Subsequent

Fig. 2.



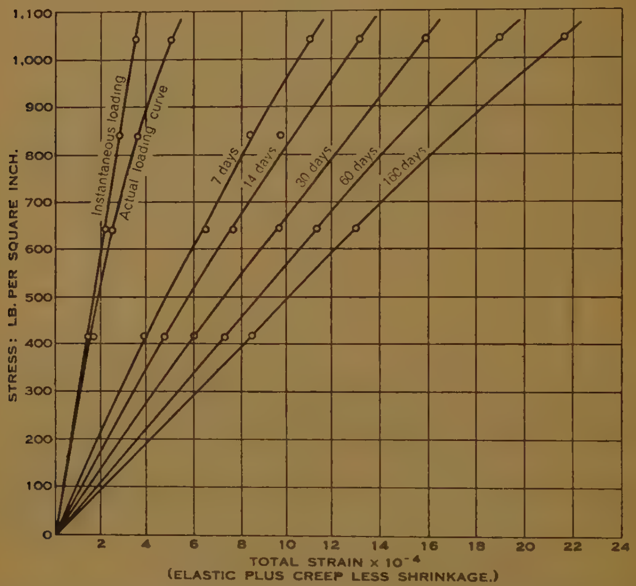
elastic tests revealed only small changes in the elastic modulus, and no corrections have been introduced for differences in elastic strain, these being only a small fraction of the total movement.

The creep–time curves are typical in shape, but represent a movement considerably greater than that found for concretes made with other classes of cement. The specimen at 1,040 lb. per square inch, which was maintained under stress for nearly 3 years, showed a creep of $2{\cdot}27 \times 10^{-6}$ inch per inch per lb. per square inch, 35 months after loading. The true modular ratio on loading is 10, assuming a value of 30×10^{6} lb. per square inch for steel, but in terms of the "effective" modulus, computed on the total strain (elastic plus creep), the ratio increased rapidly as shown in Table III and reached the very large figure of 79 after 35 months.

Such creep-figures for a 1 : 2 : 4 concrete with a cube-strength of

3,735 lb. per square inch and an elastic modulus of $3 \cdot 0 \times 10^6$ lb. per square inch are exceptional. That the large value of creep

Fig. 3.



was due to the character of the cement seemed plausible, and further experiments were made to confirm this.

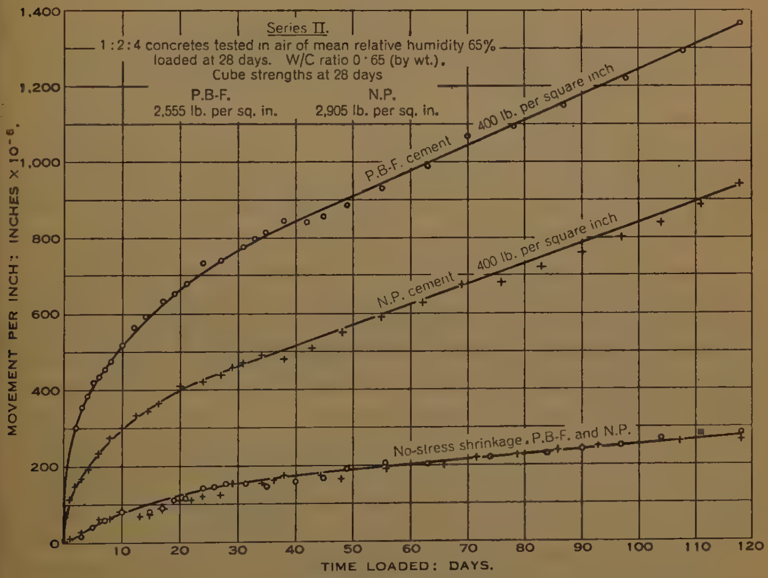
TABLE III.

Time.		Effective modulus: millions of lb. per square inch.	Modular ratio.
At loading	Elastic.	3·0	10
	Including creep.	2·12	14
After 7 days	. . . . .	0·95	32
,, 14 ,,	. . . . .	0·80	38
,, 1 month	. . . . .	0·65	46
,, 2 months	. . . . .	0·55	55
,, 3 ,,	. . . . .	0·51	59
,, 6 ,,	. . . . .	0·47	64
,, 12 ,,	. . . . .	0·43	70
,, 35 ,,	. . . . .	0·38	79

Series II.—A comparative test of normal Portland and Portland blast-furnace cement concretes was carried out using the same stress, aggregates, water/cement ratio, curing, and atmospheric

conditions. A stress of 400 lb. per square inch was employed with a 1 : 2 : 4 mix, the water/cement ratio being 0·65 by weight. Whilst it is admitted that an arbitrary choice of water/cement ratio may not give a truly comparative test with different cements, it is felt that this can have had little effect in the present case. In the standard tests, the percentages of water for gauging were 21·7 and 21·2 for normal Portland and Portland blast-furnace cements respectively, and it is probable, in view of the much greater quantity of water present at casting, that both cements were being tested under closely parallel conditions.

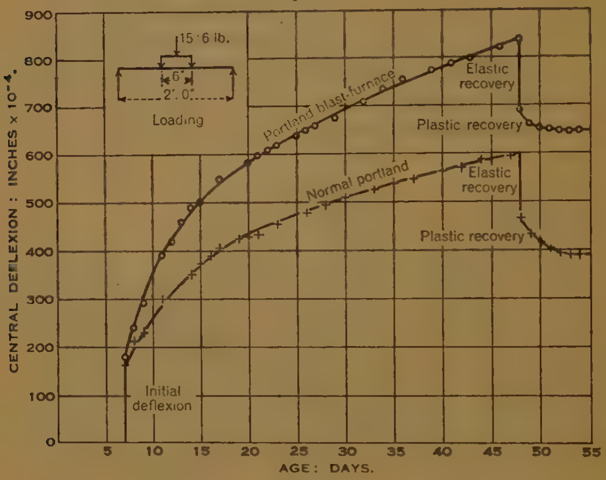
Fig. 4.



The curves of deformation with time are shown in *Fig. 4*, and it will be seen that while the shrinkages are practically the same, under stress the Portland blast-furnace cement concrete showed markedly greater creep, it being about 64 per cent. greater than that for normal Portland cement concrete at 118 days. The supposition suggested by the results of the first experiment was thus confirmed, and further evidence was supplied by flexural tests on neat-cement beams. The beams were 1 inch square in cross-section, 25 inches long, with a span of 24 inches loaded as indicated in *Fig. 5*. Central deflexions were measured to 0·0001 inch by micrometers with an electrical tell-tale to give uniformity and accuracy in reading. Again it will be

seen that the creep with Portland blast-furnace cement is considerably greater, and further comparative tests with mortar-mixes of different proportions yielded the same result in every case.

Fig. 5.



Although the ratio of the non-elastic movements was not constant, the fact that, for all tests, the average greater creep with Portland blast-furnace cement was 66 per cent. at 45 days gives some conception of the relative deformations.

Stresses Induced by Creep.

In view of the large creep of this cement, it follows that very high steel-stresses must exist in many structures in which it has been employed. If a column 12 inches square with four 1-inch diameter bars is assumed to be loaded at 28 days with 137,000 lb., then for the concrete of the first test, the stresses on loading would be 800 and 8,000 lb. per square inch in the concrete and steel respectively. Using Dr. Glanville's [1] theory for the redistribution of stress, with a creep per unit length of $1{\cdot}99 \times 10^{-6}$ per lb. per square inch after 1 year only, the increase in steel-stress is 24,000 lb. per square inch, and the shrinkage-stress from 28 days is 3,000 lb. per square inch, giving a total of 35,000 lb. per square inch. To this must be added

[1] W. H. Glanville, "The Creep or Flow of Concrete under Load." Building Research Technical Paper No. 12.

the stress induced by shrinkage up to 28 days, which would probably bring the figure up to the elastic limit for a typical mild steel. This calculation ignores the possible creep of the steel, but it should be noted that the percentage reinforcement is 2·23, and that the concrete is of a dryer mix than would normally be employed for reinforced work. With a smaller percentage of steel and with a wetter mix suitable for practical work, it is almost certain that the yield-point of the steel would be reached after a comparatively short time when further transference of load becomes impossible and a state of stress-equilibrium is reached.

Conclusion.

Much has been written already regarding the safety of a structure in such a condition. It is pointed out that compression steel in columns and beams may reasonably be called upon to carry high stresses because it is supported laterally throughout its length, that increase in tensile steel stress is small, and that, in practice, the failure of reinforced-concrete structures is rare. The use of Portland blast-furnace cement, therefore, would not appear to reduce the factor of safety, but a discriminating choice of the class of cement to be employed is indicated. For conditions demanding the minimum deformation aluminous or rapid-hardening Portland cement should be used. The Author has in mind the failure, by extensive diagonal cracking, of a party-wall constructed over a beam which showed no cracks or signs of over-stress. Normal Portland cement had been used in that case, and there seems little doubt that the trouble would have been worse had Portland blast-furnace cement been used. A practical example in which minimum deflexion is desirable is afforded in the case of a floor designed to carry mechanical plant demanding exact alignment, in which a material with little creep should clearly be employed.

On the other hand, for the avoidance of cracking the use of Portland blast-furnace cement is indicated. Reinforced structures of this material have been found to be very free from this defect, a result which follows directly from the large creep. The Author found that the shrinkage is of the same order as that of normal Portland cement concrete, and that therefore greater relief of shrinkage-stresses must be afforded by creep in tension. In general the greater yield must lead to a better accommodating action in the structure and relief to areas of concentrated stress. Portland blast-furnace cement has been used for recent dams in Germany, and whilst other considerations such as temperature-effects may have influenced

the choice, it is in this form of construction that its major advantage must lie. It is realized that only one aspect of the problem is treated here and that many other factors require consideration, but it seems reasonable to conclude that cracks due to shrinkage and unequal settlement will be reduced to a minimum by the use of this cement.

The Paper is accompanied by seven sheets of drawings, from which the Figures in the text have been prepared.

Paper No. 5081.

"Supplementary Notes on Flow Through Model Sluices.

By Herbert Addison, M.Sc., Assoc. M. Inst. C.E.

(Ordered by the Council to be published with written discussion.)[1]

TABLE OF CONTENTS.

	PAGE
Introduction	53
Part I: Comparison of existing results of submerged-sluice experiments	54
Basis of comparison	54
Typical graphs for high-head sluices	55
Typical graphs for low-head sluices	57
Transformation of results: high-head type to low-head type	57
Transformation of results: low-head type to high-head type	59
Comparison of the two methods of presentation	60
Part II: Additional experiments and conclusions therefrom	62
Free-flow experiments on low-head sluices	62
Free-flow experiments on simplified high-head sluice	62
Examination of free-flow experiments	64
Analytical treatment of free flow	65
Free-flow experiments with other forms of sluice-openings	66
Interference-effects under free-flow conditions	68
Interference-effects under submerged-flow conditions	68
Comments on submerged-flow experiments	71
General conclusions	71

Introduction.

During the past 15 years a good deal of experimental work has been carried out in Egypt on the flow of water through model sluices, but useful work remains to be done in explaining and collating the results of these experiments. The possible disposition of sluice-openings

[1] Correspondence on this Paper can be accepted until the 15th May, 1938, and will be published in the Institution Journal for October, 1938.—Sec. Inst. C.E.

and the conditions of flow may roughly be classified as follows :—

(i) Free flow through high-head sluices (water discharging freely into air on the downstream side).
(ii) Submerged flow through high-head sluices (downstream water-level above sluice-openings).
(iii) Free flow through low-head sluices.
(iv) Submerged flow through low-head sluices.

Experiments bearing on disposition (i) have already been described [1] by Dr. H. E. Hurst and Mr. D. A. F. Watt. At a later date Dr. Hurst extended his researches to submerged-sluice models, disposition (ii), and published them under the title "Further Experiments on the Discharge of Models of Sluices." [2] The Author's own experiments on submerged low-head sluices, disposition (iv), have already been described.[3] As regards disposition (iii), however, no published material appeared to be available, and the Author therefore carried out in the laboratories of the Royal School of Engineering, Giza, the experiments described in Part II of the present Paper. The whole range of experimental conditions being thus fairly adequately covered, it has become possible to discover whether the respective results are characteristic only of the particular type of sluice examined or whether they are of general application.

PART I.

COMPARISON OF EXISTING RESULTS OF SUBMERGED-SLUICE EXPERIMENTS.

Basis of Comparison.

In their published form the results of Dr. Hurst's experiments on submerged high-head sluices (disposition (ii), above), cannot be directly compared with the Author's results obtained from low-head submerged sluices (disposition (iv), above), because of the difference in the manner in which the observations were recorded ; whereas Dr. Hurst plotted his observations so as to show the correlation

[1] H. E. Hurst and D. A. F. Watt, "The Similarity of Motion of Water through Sluices and through Scale Models: Experiments with Models of Sluices of the Assuan Dam." Minutes of Proceedings Inst. C.E., vol. ccxviii (1923–24, Part II), p. 72.

[2] Ministry of Public Works, Egypt: Physical Department Paper No. 25.

[3] "The Flow of Water through Groups of Sluices: Experiments on Scale Models, &c." Inst. C.E. Selected Engineering Paper No. 105 (1931).

between discharge and upstream level, for fixed downstream conditions, the Author maintained constant rates of discharge and worked out the effect of variations of downstream depth on the coefficient of discharge of the sluice-openings. The following paragraphs show how the results obtained by one experimenter may be presented in the form chosen by the other, and that when so arranged the results are mutually in agreement.

Typical Graphs for High-Head Sluices.

As typical of the general behaviour of high-head sluices, graphs relating to a $\frac{1}{50}$th-scale model of an Assuan dam sluice have been chosen, and they are reproduced in *Fig. 1.** Since the prototype is a Type D sluice (R.L. 87·65 metres), the sluice-way of the model measured 14 centimetres by 4 centimetres, and as, throughout the particular range of experiments in question, the gate was raised 4 centimetres, the actual sluice-opening was 4 centimetres square. The shape of the model in relation to the upstream and downstream water-surfaces is shown in *Fig. 1.*

As Dr. Hurst explains, three types of flow are to be distinguished as the upstream depth changes: (*a*) free conditions, during which, although the downstream water-surface is above the top of the sluice-opening, and the opening is thus technically submerged, yet the presence of a standing wave in the sluiceway permits the same flow to pass as if the jet were discharging freely into air; (*b*) transition conditions, during which the downstream water-level has a modified influence on the flow; and (*c*) submerged conditions, during which the flow is wholly dependent on the difference between upstream and downstream levels.

Using the symbols

q to denote the discharge,
a „ „ area of sluice-opening,
H „ „ upstream depth over the sill,
h „ „ downstream depth over the sill,
C, F „ „ constants for a particular gate-opening, downstream depth, and range of discharge,
g „ „ acceleration of gravity,

Dr. Hurst found that free and transition flow, (*a*) and (*b*) above, may be expressed by the relationship

$$q = Ca\sqrt{2g(H - F)}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

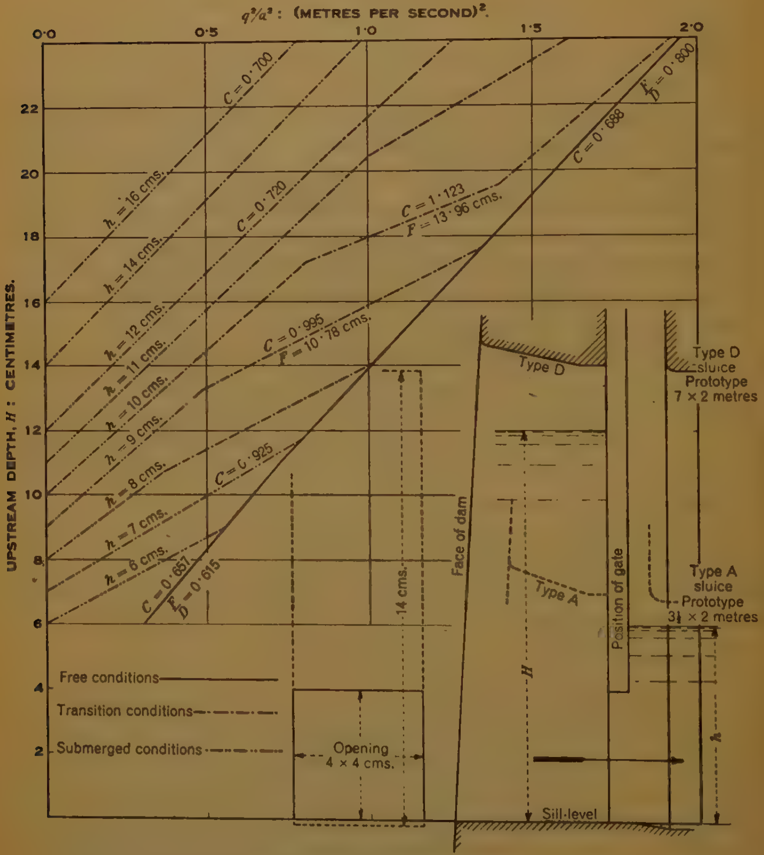
* Based on Plate 3 of Physical Department Paper No. 25 (footnote (²), p. 54).

and that submerged flow, (*c*), may be expressed by the relationship

$$q = Ca\sqrt{2g(H - h)} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Consequently if, for a given downstream depth, values of (nominal

Fig. 1.



Flow Through $\frac{1}{50}$th-Scale Model of Assuan Type-D Sluice (R.L. 87·65 Metres).

velocity)$^2 = (q/a)^2$ are plotted against upstream depth H, as in *Fig. 1*, the resulting graphs will consist of straight lines, the change in slope corresponding to a change from one type of flow to another. For example, taking a downstream depth h of 9 centimetres, the flow will be submerged as the upstream depth rises from 9 to 13·3

centimetres, transitional as H increases from 13·3 to 17·6 centimetres, and free for all higher values of H (*Fig. 1*).

Typical Graphs for Low-Head Sluices.

The Author's experiments on submerged low-head sluices* were made on a model, built to a scale of $\frac{1}{25}$th, of four vents of the (original) Assiut barrage, each vent being 20 centimetres wide as shown in plan in *Figs. 2*. In the experiments here selected, the gate-openings were in turn 6·07, 9·00, and 12·00 centimetres, the flow being directed between the lower gates and the flat floor; the results are given in *Figs. 2*, which is reproduced from *Fig. 8* of Selected Engineering Paper No. 105.*

Using the symbols

q to denote the discharge per vent,
b ,, ,, width of gate-opening,
D ,, ,, height of gate-opening,
d_u ,, ,, upstream depth over the floor (corresponding to H in the high-head experiments),
d_d ,, ,, downstream depth over the floor (corresponding to h in the high-head experiments),
h_{vu} ,, ,, velocity head in the upstream approach-channel,

values of the coefficient of discharge C_d were calculated from the formula

$$q = C_d bD\sqrt{2g(d_u + h_{vu} - d_d)} \quad . \quad . \quad . \quad . \quad (3)$$

and the values of C_d plotted against d_d, as in *Figs. 2*. Here each graph represents a series of experiments at a fixed discharge. It will be observed that in general the value of the coefficient of discharge diminishes as the downstream depth increases; also that, while at great depths and large gate-openings the value of C_d is independent of the rate of flow, yet at lower downstream depths the value of the coefficient tends to increase as the discharge increases.

Transformation of Results: High-Head Type to Low-Head Type.

In order to transform the results of the high-head sluice-experiments presented in *Fig. 1* into the form used in *Figs. 2*, it is necessary to draw on *Fig. 1* a series of verticals corresponding to values of $(q/a)^2$ of, for example, 0·25, 0·5, 0·75, and 1·00. After reading off the appropriate values of upstream depth $H = d_u$, and downstream

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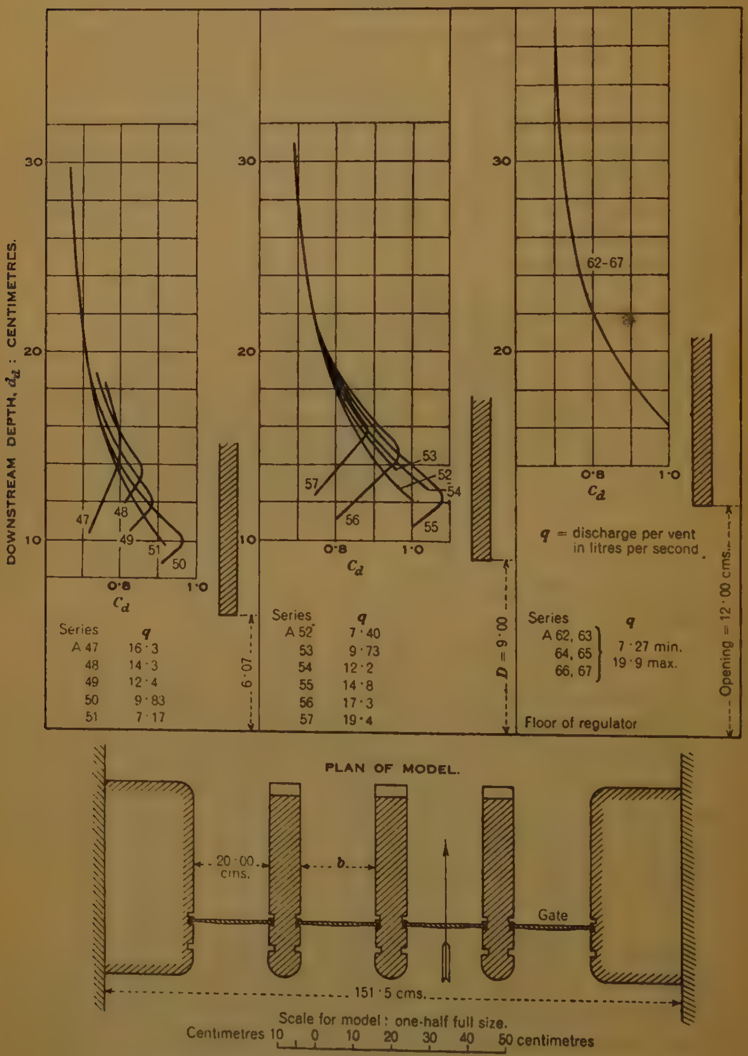
* Footnote ([3]), p. 54.

depth $h = d_d$, these can be inserted in equation (3) above and a series of values of C_d calculated for steady rates of flow of $q = 0{\cdot}8$,

Figs. 2.

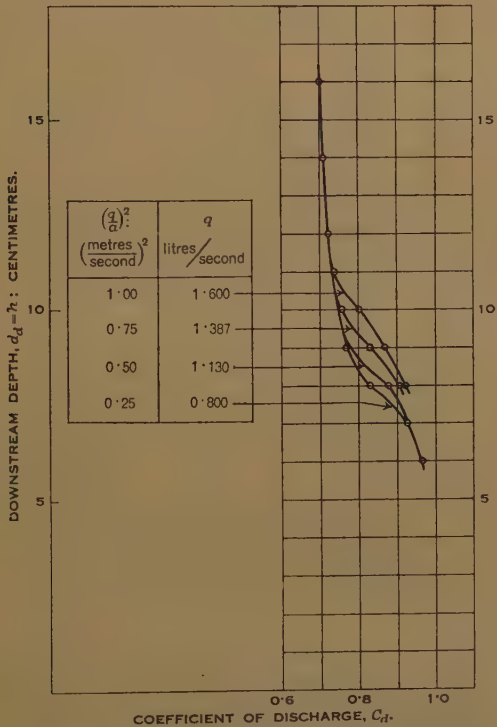


FLOW THROUGH $\frac{1}{25}$TH-SCALE MODEL OF ASSIUT BARRAGE.

$q = 1{\cdot}130$, $q = 1{\cdot}387$, and $q = 1{\cdot}600$ litres per second. The velocity-head h_{vu} in the upstream approach-channel is assumed to be zero.

Plotting now C_d against d_d, as in *Figs. 2*, the graphs reproduced in *Fig. 3* are obtained; the general resemblance between the two families of curves is unmistakable.

Fig. 3.



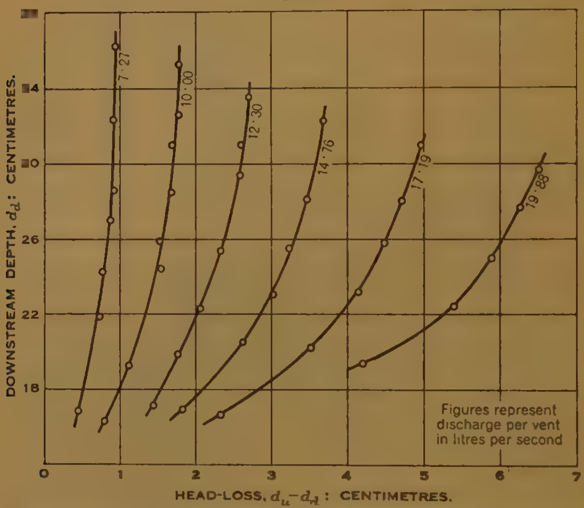
FLOW THROUGH HIGH-HEAD SLUICE-MODEL.

Transformation of Results: Low-Head Type to High-Head Type.

Although the information given in *Figs. 2* would suffice to permit graphs similar to *Fig. 1* to be prepared showing the performance of low-head sluices, the process was actually facilitated by using the Author's original experimental data. Taking, for example, the observations relating to flow through sluices open 12·00 centimetres, graphs between downstream depth and head lost were plotted as in *Fig. 4*, for each rate of flow. Drawing horizontals representing $d_d = 18$ centimetres, $d_d = 22$ centimetres, etc., values of $d_u - d_d$ can be read off for each rate of flow, and hence equivalent values of $H = d_d + (d_u - d_d) + h_{vu}$ are obtainable; in this way *Fig. 5* has

been prepared. Again there is close agreement between *Fig. 1*, relating to high-head sluices, and *Fig. 5*, relating to low-head sluices, in spite of the difference in the shape of the sluices and in the operating conditions.

Fig. 4.



FLOW THROUGH FOUR LOW-HEAD SLUICE-OPENINGS 20 CENTIMETRES WIDE BY 12 CENTIMETRES HIGH.

Comparison of the Two Methods of Presentation.

Having found that the results from either type of sluice-model may be represented in either of two ways, the relative advantages of the two methods may be discussed.

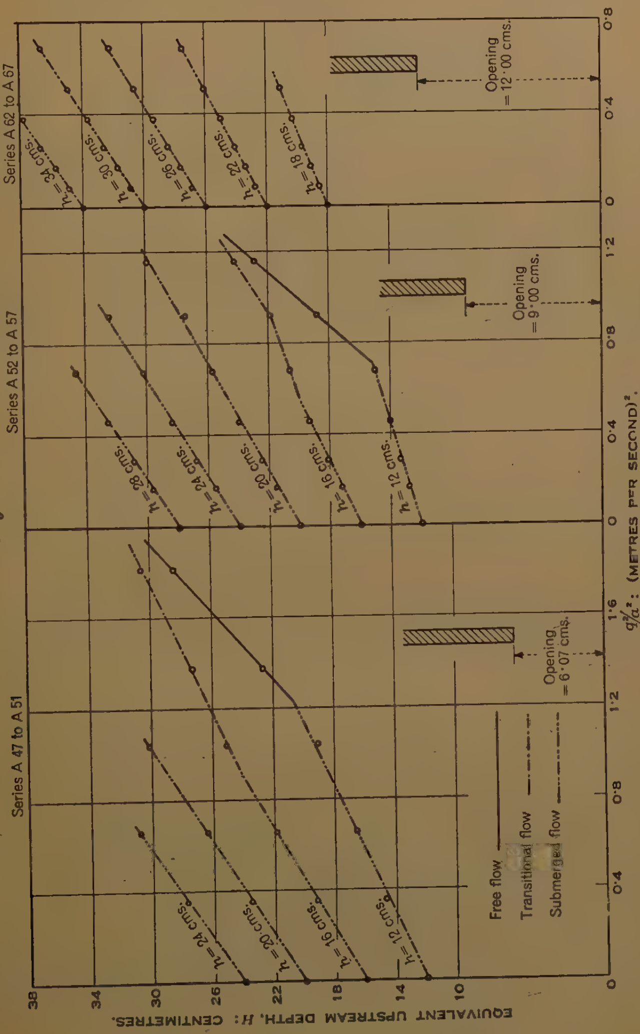
(i) The chief advantage of the "constant downstream level" method of plotting (*Figs. 1* and *5*), is that it yields graphs all of which are straight lines that can be represented by equations of a simple type (Equations (1) and (2)).

(ii) The chief advantage of the "constant discharge" method of plotting (*Figs. 2* and *3*) is that the graphs are much more compact than those of the alternative method. When the flow is of the fully-submerged type, as in *Figs. 2*, with a 12·00-centimetre gate-opening, a single curve will represent the whole range of discharges and water-levels. On the other hand, the equations required to represent the curves are relatively complex.

(iii) Whereas in the "constant downstream level" method, the change from transition flow to submerged flow is manifested by a

change in slope of the graph, the corresponding change in the type of flow is shown in the " constant discharge " method by the coalescence of a number of curves into a single one. The change from

Fig. 5.



FLOW THROUGH LOW-HEAD SLUICE-MODEL.

transition flow to free flow, which is marked by the formation of a standing wave in the sluiceway, is shown also by a change in slope of the " constant downstream level " graph, but by a more or less well-defined cusp in the " constant discharge " graphs.

Part II.

Additional Experiments and Conclusions Therefrom.

Free-Flow Experiments on Low-Head Sluices.

These experiments were made on the $\frac{1}{25}$th scale model of the Assiut barrage shown in plan in *Figs. 2* (p. 58); in all cases the water was directed between the lower gates and the flat floor of the model, escaping freely on the downstream side. In some of the experiments four vents were in use, and in others, two vents or only one. The maximum upstream depth of water was from 30 to 35 centimetres. The free-flow formula (1) (p. 55) was found to be applicable in all cases, the values of the constants C and F being recorded in Table I.

Table I.—Flow through Low-Head Sluices.

(Assiut $\frac{1}{25}$th Scale Model.)

Openings 20·00 centimetres wide, flow beneath gates, supported jet.

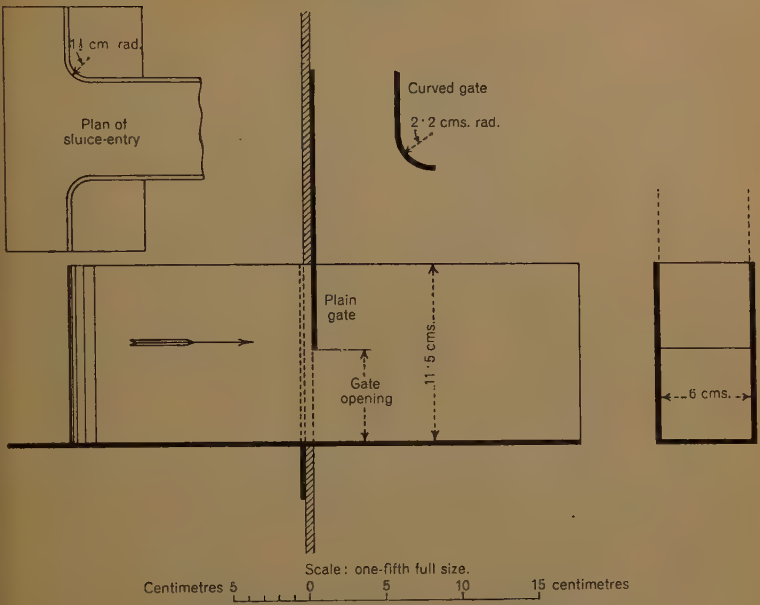
Number of vents in operation . .	4	4	2	2	1
Height of openings, D: centimetres	3·00	3·98	4·00	6·00	9·00
Values of constants C	0·618	0·618	0·616	0·607	0·615
Values of constants F : centimetres .	1·72	2·28	2·44	3·60	5·70
Values of constants $\frac{F}{D}$	0·57	0·57	0·61	0·60	0·63

Free-Flow Experiments on Simplified High-Head Sluice.

These tests were made on a model specially built of sheet brass, giving the same gate-openings as a $\frac{3}{100}$th scale model of an Assuan Type A (R.L. 100) sluice, but having the simplified form shown in *Figs. 6*; the floor of the sluiceway is quite flat, and there are no vertical grooves for the gate. Some of the experiments were made with a plain straight gate, and others with a gate curved at the bottom to a radius of 2·2 centimetres. The results are shown in *Fig. 7* and in Table II; for comparison, the results obtained on models of an actual Type A Assuan sluice are reproduced in Table III: these are mean values abstracted from Table I of a Paper by Messrs. Hurst and Watt.[1]

[1] "The Measurement of the Discharge of the Nile through the sluices of Aswan Dam." Ministry of Public Works, Egypt: Physical Department Paper No. 24.

Fig. 6.



SIMPLIFIED HIGH-HEAD SLUICE-MODEL.

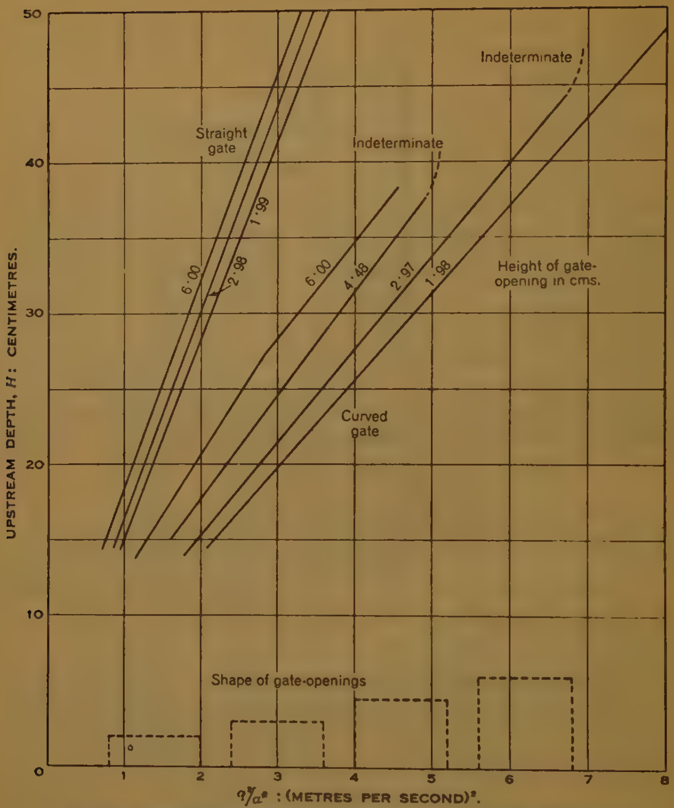
TABLE II.—FLOW THROUGH SIMPLIFIED HIGH-HEAD SLUICE MODEL.
(See *Figs. 6* and *7*: Nominal width = 6 centimetres, supported jet).

Type of gate.		Straight.			Curved.				
Height of opening, D: centimetres		1·99	2·98	6·00	1·98	2·97	4·48	6·00 Low heads	6·00 High heads
Values of constants	C . .	0·622	0·612	0·610	0·941	0·910	0·867	0·798	0·889
	F: centimetres	1·9	2·8	4·7	2·5	3·0	4·1	4·7	9·2
	$\frac{F}{D}$.	0·95	0·94	0·78	1·25	1·01	0·91	0·78	1·53

TABLE III.—FLOW THROUGH $\frac{3}{100}$TH MODEL OF ASSUAN TYPE "A" SLUICE.
(R.L. 100.)
Nominal width = 6 centimetres, supported jet.

Height of opening, D: centimetres .		3	4·5	6	7·5
Values of constants . . .	C . .	0·671	0·685	0·696	0·729
	$\frac{F}{D}$.	0·73	0·81	0·79	0·85

Fig. 7.



FLOW THROUGH SIMPLIFIED HIGH-HEAD SLUICE-MODEL.

Examination of Free-Flow Experiments.

A study of Tables I, II and III shows that, although in general the free-flow formula $q = Ca\sqrt{2g(H - F)}$ is applicable, yet the proportions of the sluice and sluiceway have a marked effect on the values of the constants C and F. In the actual Assuan model, Table III, which is of relatively complicated form, having an upstream bell-mouth, a sluice-well, and a drop in the floor just downstream of the gate, as indicated in the cross section, *Fig. 1*, the effect of increasing the gate-opening from 3 to 7·5 centimetres is to raise the value of the coefficient C from 0·671 to 0·729. With the other two models, however (Tables I and II), the values of C obtained with a plain gate and a flat floor are remarkably consistent, rarely diverging by more than 1 per cent. from a mean of 0·615. The use of a

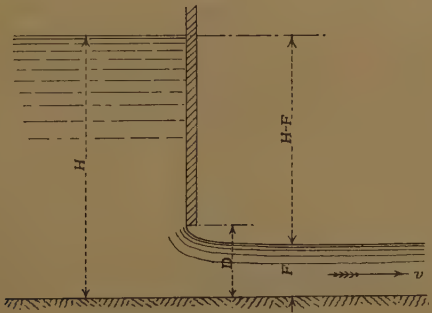
curved gate naturally increases the value of C (Table II). It is evident both from this Table and from the graphs, *Fig. 7*, that the use of a curved gate has no advantages from the point of view of water-measurement. Among other objections, there is a tendency at high heads for the flow to become indeterminate; this is because the water flowing down the inner face of the gate begins to spring clear of the curved lower lip, the jet thus resembling more and more the fully contracted jet issuing beneath a straight gate.

There is no very clear correlation between the value of the ratio $\frac{F}{D}$ and the gate-opening or the shape of the opening. Whereas in Table II this ratio diminishes as the opening increases, yet in Tables I and III there is a tendency for the ratio to increase as the opening increases.

Analytical Treatment of Free Flow.

An explanation of the constancy of the values of C and F in the free-flow formula is suggested in *Fig. 8*, where water is shown

Fig. 8.



FLOW WITH SUPPORTED JET

flowing under a plain gate and over a flat floor. The ideal velocity at the *vena contracta*, assumed uniform across the whole section of the jet, is that due to the head $H - F$, namely $v = \sqrt{2g(H - F)}$, where F is the depth at the *vena contracta*. The discharge through the opening of width b is thus $Fb\sqrt{2g(H - F)}$; that is, $q = \frac{F}{D} \cdot a\sqrt{2g(H - F)}$.

According to this interpretation, the value of the coefficient C should, under ideal conditions, be numerically equal to the coefficient

of contraction $\frac{F}{D}$, and it may be seen from Table I that in the head experiments this identity is nearly fulfilled (mean value $C = 0{\cdot}613$, mean value of $\frac{F}{D} = 0{\cdot}598$).

The theoretical value of $\frac{F}{D}$, and therefore of C, has been worked out by Lord Rayleigh,[1] and was found to be $\frac{\pi}{\pi + 2} = 0{\cdot}612$, with which the experimental mean value of 0·615 quoted above (p. 64) agrees quite well.

Free-Flow Experiments with Other Forms of Sluice-Openings.

Although the application of the formula $q = Ca\sqrt{2g(H - F)}$ only appears to be justified when fully-supported jets are considered (that is, jets supported at the bottom and sides), experiments were made to see whether the formula would fit other forms of openings. (*a*) The $\frac{1}{25}$th-scale model of the Assiut barrage shown in *Figs. 2* was used for free-flow experiments in which the water flowed between the upper gates and lower gates 6·95 centimetres high. The results are recorded in Table IV. (*b*) A plain brass partition, 3 millimetres

TABLE IV.—FLOW THROUGH LOW-HEAD SLUICES.

(Assiut $\frac{1}{25}$th Scale Model.)

Openings 20·00 centimetres wide, flow between gates, lower gates 6·95 centimetres high.

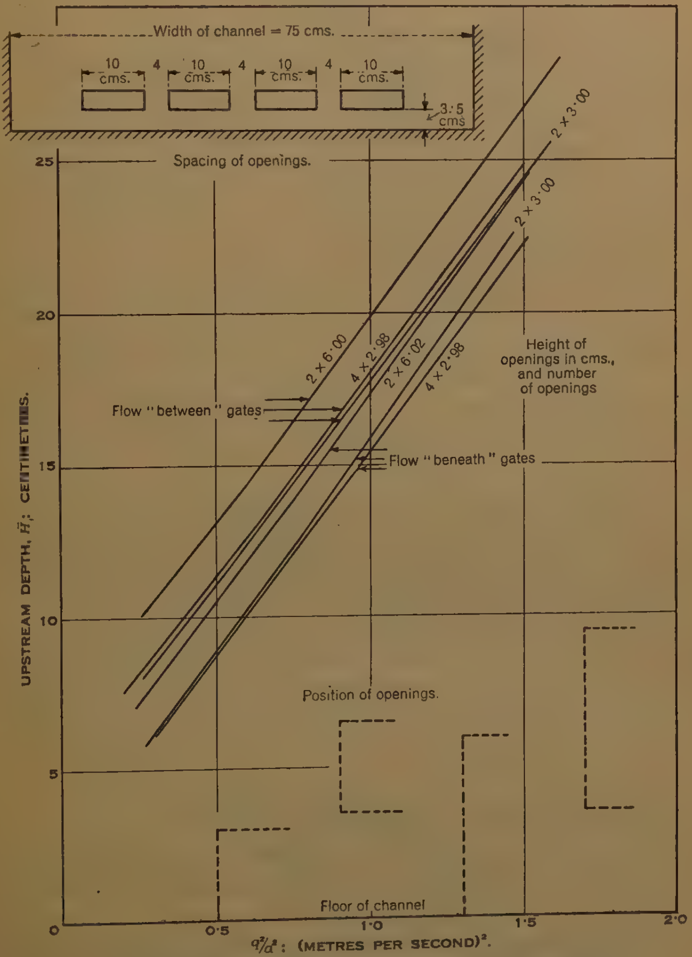
Number of vents in operation		2	2	1
Height of openings, D: centimetres		4·00	6·00	8·00
Values of constants	C	0·638	0·626	0·629
	F (centimetres above bottom of opening)	1·64	2·30	3·60
	$\frac{F}{D}$	0·41	0·38	0·45

thick, with openings pierced as shown in *Fig. 9*, was fixed across a uniform channel 75 centimetres wide. The relative spacing and proportions of the openings were thus identical with, and their dimensions were one-half of, the openings in the $\frac{1}{25}$th Assiut model just mentioned. The openings thus corresponded exactly with those of the $\frac{1}{50}$th scale model "B" used in the Author's experiments described in Selected Engineering Paper No. 105.† The results of the present experiments are given in Table V (p. 68) and in *Fig. 9*.

[1] "Hydrodynamical Notes," *Phil. Mag.*, vol. xxi (1911) p. 177.
† Footnote (³), p. 54.

variably the performance of the openings could be represented
raight lines, but in most instances a change of slope was

Fig. 9.



Flow Through Simplified Low-Head Sluice-Model.

observed, the values of C and of $\frac{F}{D}$ for high heads being slightly different from the values for low heads. The average value of C for unsupported jets (flow between gates) did not differ greatly from the corresponding value for supported jets (flow beneath gates), but

Table V.—Flow through Simplified Low-Head Sluice Model.
(See *Fig. 9.*)
Openings 10·00 centimetres wide.

		Flow beneath gates.			Flow between gates.		
Number of vents in operation		2	4	2	2	4	2
Nominal height of opening, D: centimetres		3·0	3·0	6·0	3·0	3·0	6·0
Height of bottom of opening above floor: centimetres		0	0	0	3·5	3·5	3·5
Values of constants: Small flows and heads	C	0·617	0·620	0·620	0·632	0·635	0·636
	$\frac{F}{D}$	0·74	0·72	0·65	0·41	0·52	0·56
Values of constants: Large flows and heads	C	0·594	0·611	0·604	0·619	0·613	0·613
	$\frac{F}{D}$	0·51	0·63	0·55	0·31	0·32	0·46

whereas the value of $\frac{F}{D}$ was always greater than 0·5 when the water flowed beneath the gates, it was nearly always less than 0·5 when the water flowed between the gates.

Interference-Effects under Free-Flow Conditions.

Only inconclusive evidence concerning interference-effects is to be found in the results so far presented; neither in Table I nor in Table V are the values of the constants seen to be sensibly altered by using all four openings instead of the outer two openings only. This may be compared with the results of the Author's original experiments,[1] where the only instance in which marked interference did not occur was when free flow took place through fully-opened vents, under broad-crested-weir conditions.

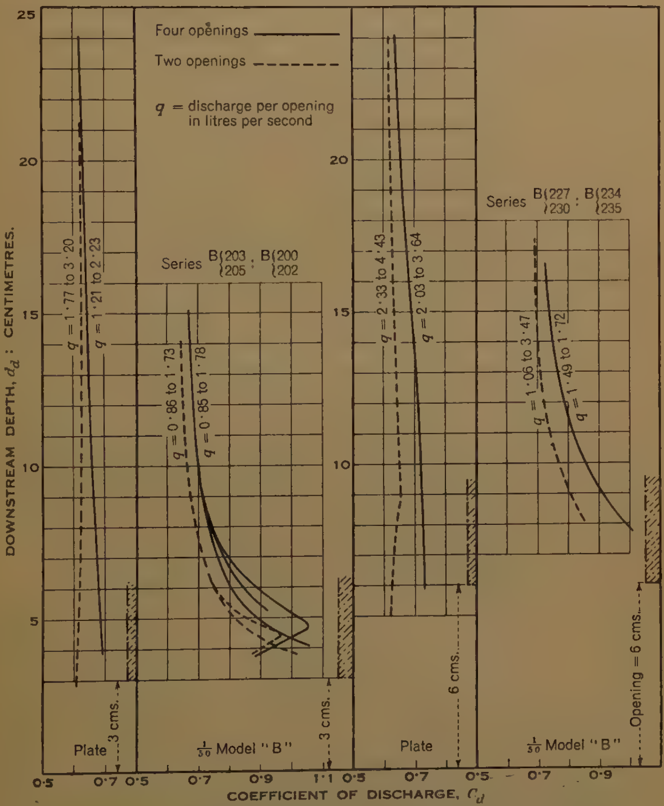
Interference-Effects under Submerged-Flow Conditions.

Experiments were made on the simplified low-head sluice-model, *Fig. 9*, with the object of detecting interference-effects, if any, when submerged flow took place through the openings; a direct comparison then became possible between the behaviour of these plain openings and the behaviour of identical openings in the vents of the $\frac{1}{50}$th scale model of the Assiut barrage (Model "B"), the width of the channel and the spacing of the gauge-points being maintained unchanged. As in the original experiments,[1] each series consisted of a set of observations made at a uniform rate of discharge, with

[1] Footnote ([3]), p. 54.

varying upstream and downstream levels. Usually three series of observations were made for each combination of openings; from these, the values of the coefficient of discharge C_d were worked out

Figs. 10.



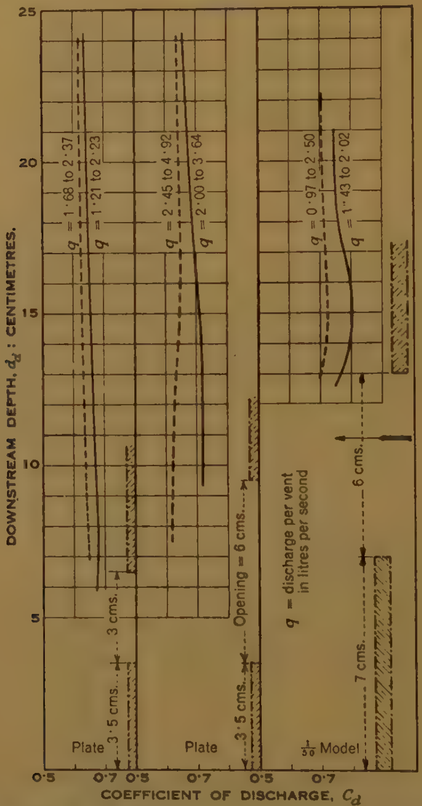
SUBMERGED FLOW THROUGH LOW-HEAD SLUICE-MODEL.
(FLOW "BENEATH" GATES.)

from formula (3), $q = C_d bD\sqrt{2g(d_u + h_{vu} - d_d)}$, and plotted against the downstream depth as in *Figs. 2.*

In *Figs. 10* the results of experiments with water flowing "beneath" the gates are recorded for two and for four openings 10 centimetres wide, with heights of opening of 3 centimetres and of 6 centimetres, the bottom of the openings being coincident with the flat floor of the channel. For comparison, the equivalent graphs relating to the $\frac{1}{50}$th-scale model "B" are reproduced from *Figs. 10*

of the earlier Paper.[1] The divergencies between the two sets of curves are thus indicative of the changes in the flow resulting from the suppression of the upstream noses and downstream piers, whose

Figs. 11.



Submerged Flow Through Low-Head Sluice-Model.
(Flow "Between" Gates.)

shape can be seen from *Figs. 2*. *Figs. 11* show the results of experiments on flow "between" gates, the broken lines referring to two openings 10 centimetres wide and the full lines to four openings 10 centimetres wide, the bottom of all the openings being 3·5 centimetres above the floor of the channel. As no experiments with a lower gate 3·5 centimetres high were made on the $\frac{1}{50}$th-scale model

[1] Footnote (3), p. 54.

"B," the results of experiments on model "B" with lower gates 7 centimetres high have been plotted for comparison in *Fig. 11.* (These results were not recorded in the earlier Paper.)[1]

Comments on Submerged-Flow Interference-Experiments.

(*a*) Interference-effects are always present, the closing of two of the four openings always reducing the value of the coefficient of discharge C_d for a given downstream depth ; this reduction ranged from 2 per cent. or less when the downstream depth was great, to 10 per cent. or more when the depth was small.

(*b*) For a given downstream depth, the interference-effect, or percentage reduction in C_d following on the closure of the two central openings, was greater for openings 6 centimetres high than it was for openings 3 centimetres high.

(*c*) For a given depth and disposition of the openings, the reduction of C_d caused by interference was roughly the same for the simplified sluice-model (plate) as it was for the actual barrage-model.

(*d*) Under given conditions of gate-openings and downstream depths, the value of the coefficient of discharge for the plate was invariably less than it was for the actual model ; at low levels, with flow beneath gates, a difference of 30 per cent. might be reached.

In general, then, it may be said that anything that increases the ratio

$$\frac{\text{Total area of openings}}{\text{Area of waterway in downstream channel}}$$

will tend to increase the interference-effect, a conclusion which agrees with the results of the Author's earlier experiments.[1]

Comparing the simplified plate-model with the actual barrage-model "B," the suppression of the downstream part of the piers, especially with flow beneath gates, diminishes the opportunities for regain of head in the sluiceways and downstream channel and so causes a reduction in the absolute value of the coefficient of discharge. This reduction is augmented by the side contraction imposed on the jets issuing through the openings in the simplified plate model.

General Conclusions.

(i) The experiments on high-head submerged sluices [2] and those on low-head submerged sluices[1] gave results whose general tendencies are mutually in agreement.

[1] Footnote (3), p. 54.
[2] Footnote (1), p. 54.

(ii) Under free-flow conditions, all the experiments on various types of openings yielded results that could be represented by straight-line graphs.

(iii) Under free-flow conditions, rectangular sharp-edged openings having a lower edge coincident with the flat horizontal floor of a sluiceway that is free from large irregularities may be expected to give values of the coefficient C within a few per cent. of the theoretical value 0·612. In favourable circumstances the ratio $\frac{F}{D}$ may also have a value not far from 0·612.

(iv) Under submerged-flow conditions, interference-effects may be no less important with a pierced flat plate than they are with an equivalent scale-model regulator.

The Paper is accompanied by ten sheets of diagrams, from which the Figures in the text have been prepared.

Paper No. 5098.

"Shearing Stresses in Gravity Dams."

By Serge Leliavsky.

(Ordered by the Council to be published with written discussion.)[1]

TABLE OF CONTENTS.

	PAGE
Introduction	73
Methods at present in use for the computation of shearing stresses in gravity dams	76
General formula for the calculation of shearing stresses	82
New graphical method for the computation of shearing stresses	90
Conditions when the reservoir is empty	92
Application of the general formula to other structures	94

Introduction.

In the earliest period of the modern history of engineering sciences, when little was known about the testing of structural materials, it was more or less generally believed that failure occurred when, and only when, the normal stress exceeded a certain definite limit, irrespective of any other stresses that might occur at the same point. However, as experimental methods gradually developed it soon became evident that this assumption could not be made to agree with the results of tests; two other theories were then put forward in which the criterion of failure was taken to be the maximum strain (St. Venant's theory) and the maximum shearing stress (Coulomb's theory).

Further experimental evidence showed that neither of these two elementary hypotheses could reconcile all the apparently contradictory information concerning the ultimate conditions under which failure took place, and a number of more involved criteria were suggested by different writers, the intention being to find a general theory that would explain all the known facts relating to the behaviour of structural materials under the effect of complex stresses. For instance, Becker's theory is based on a combination of the

[1] Correspondence on this Paper can be accepted until the 15th May, 1938, and will be published in the Institution Journal for October, 1938.—Sec. Inst. C.E.

maximum-strain and the maximum-shear criteria; Reyto's theory (1887) takes into account the "internal friction"; Beltrami's theory (1885) and that of Haigh (1903) contain an original principle, namely, that the failure is supposed to depend on the stored amount of mechanical energy (per unit of volume of material). This criterion has recently been given a more developed form by Schleicher (1926). The amendment consists in the assumption that the critical amount of energy, instead of being taken to be constant, is a function of the average normal stresses at the point. This amendment is a marked improvement. It appears, however, that all the energy criteria are open to serious criticism, because they cannot explain the tendency of the material to crack along definite geometrical surfaces, which are determined by the direction and the character of the forces representing the cause of the failure in each particular case.

Another trend of thought originated from the theory of Coulomb. In 1885, Duguet suggested a correction of Coulomb's criterion by assuming that the breaking intensity of the shearing stress depends on the normal stress. A similar principle formed the basis of the graphical criterion proposed about 15 years later by Mohr; another theory of the same group was developed in 1908 by Prandtl, who followed the general lines of Mohr's hypothesis, but, instead of a linear equation, introduced a more elaborate relation between the critical values of shear and normal stresses.

According to this group of theories—which is probably the most popular one among structural engineers at present—it appears that failure of masonry or concrete, when subject to complex stresses, can generally be attributed to the combined effect of shearing and normal stresses acting at the same time, at the same point, and on the same plane. It would, therefore, follow that failure caused by normal stresses alone does not occur in practice except under very unusual circumstances, the probability of which is necessarily small as compared with the more general case when tension or compression are combined with shear in causing the material to break.[1]

To give an instance of some of the latest views on the subject, attention is called to an article on dam design[2] published in 1934 by Professor Karl Terzaghi. It is not intended to discuss here the main subject of that article—which refers to the action of uplift—

[1] Further information on the history of the theories concerning the causes of rupture is given by K. Kammüller, "Die Theorie de Gewichtsstaumauern" (Berlin, 1929); by S. Timoshenko and J. M. Lessels, "Applied Elasticity" (London, 1928); and in other works on applied mechanics.

[2] "Die wirksame Flächenporosität des Betons," Zeitschrift des Österreichischen Ingenieur- und Architekten-Vereines, 1934, Nos. 1–2, p. 1 *et seq.*

but, in so far as the shearing stresses are concerned, it is instructive to note that Mohr's graphical criterion forms an important element of the considerations which serve to substantiate Professor Terzaghi's conclusions. The diagram representing the critical conditions is taken to be approximately rectilinear, and, if represented analytically, would correspond to the equation

$$\tau_{cr} = A + B\eta_{cr},$$

where τ_{cr} denotes the critical value of the shearing stress which, in combination with η_{cr} or with any normal stress less than η_{cr}, causes the material to fail;

η_{cr} ,, the normal stress (positive, if compression, and negative, if tension) acting at the same point and on the same plane as τ_{cr}, and

A and B are two coefficients assumed to be approximately constant.

From the results of several hundreds of experiments with test-pieces made of cement and sand, A. Brandtzaeg [1] found that B lies between the limits of tan 36° and tan 44° (for values of η_{cr} ranging from 0 to 280 atmospheres). Another set of tests cited by Professor Terzaghi, namely the torsion experiments of A. Hertwig,[2] gave $B = \tan 48° 30'$. On the basis of these figures Professor Terzaghi assumes $B = \tan 36° = 0{\cdot}727$ as a miminum value. According to his own experiments it appears that the numerical values of A corresponding to $B = 0{\cdot}727$ are as follows[3]:—

(*a*) Test-pieces containing 600 kilograms of cement per cubic metre: 1478 tonnes per square metre.

(*b*) Test-pieces containing 400 kilograms of cement per cubic metre: 1355 tonnes per square metre.

(*c*) Test-pieces containing 236 kilograms of cement per cubic metre: 169 tonnes per square metre.

Thus, the equations representing the ultimate breaking conditions

---

1 F. E. Richart, A. Brandtzaeg and R. L. Brown, "A Study of the Failure of Concrete under Combined Compressive Stresses." Univ. of Illinois Eng. Exp. Stn. Bulletin No. 185. November, 1928.

2 A. Hertwig, A. Luden and H. Hetermann, "Zur Frage der Bruchsicherheit der Staumauern." *Deutsche Wasserwirtschaft*, No. 7, 1933.

3 Though Prof. Terzaghi does not give the values of A directly, they can be calculated from the formula $A = \frac{c_K}{2} \tan 27°$, where c_K denotes the stress shown in the upper line of Table 3 appearing on p. 6 of his article.

for the respective materials made of cement and sand are found to be :—

(a) $\tau_{cr} = 1478 + 0{\cdot}727\ \eta_{cr}$ tonnes per square metre.
(b) $\tau_{cr} = 1355 + 0{\cdot}727\ \eta_{cr}$ „ „
(c) $\tau_{cr} = 169 + 0{\cdot}727\ \eta_{cr}$ „ „

According to these formulas the values of τ_{cr} calculated for $\eta_{cr} = 0$ are less than those of η_{cr} for $\tau_{cr} = 0$. These results indicate that for masonry and concrete shearing stresses are more dangerous than tension, a conclusion which in the light of the more conservative views on the subject might appear to be rather paradoxical. It should be remembered, however, that the case to which this result is intended to refer is that of pure shear, that is to say, shear unaccompanied by normal stress. Should there be any compression acting on the same plane, the maximum safe intensity of shearing stress would rapidly rise.

It follows that the safety of a dam design depends not only on the value of the maximum shearing stresses, but also, and essentially, on the manner in which they are distributed over the different points of the cross-section. It might, therefore, appear to be rather fortunate that the maximum shearing stresses in a gravity dam of the usual triangular type coincide in space with the zone of the highest compression-intensities.

Whether these conclusions—and the theories from which they are derived—are taken to be true may be, to a certain extent, a matter of personal opinion, but, apart from all that has been said and written on the shearing stresses themselves, it will be remembered that in analysing a dam profile they serve also to determine the normal stresses acting on vertical planes.

In general, it is almost evident that a comprehensive picture of the state of stress in the various points of a dam profile could scarcely be obtained without an exhaustive analysis of the shearing stresses. Yet, as will be seen from the following section of this Paper, the computation of these stresses by the usual methods leads to certain difficulties.

Methods at Present in Use for the Computation of Shearing Stresses in Gravity Dams.

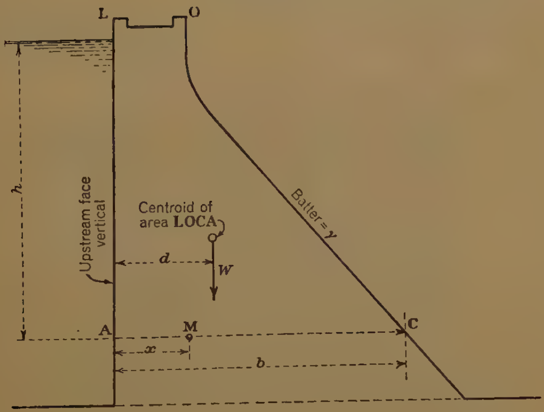
The formula given by Mr. E. P. Hill, M. Inst. C.E., was first published in 1908.[1] According to that formula the intensity of shearing

[1] "Stresses in Masonry Dams," Minutes of Proceedings Inst. C.E., vol. clxxii (1907–1908, Part II), p. 134.

stress is determined as follows :—

$$\tau = \{4W\gamma(b - 3d) + \epsilon h^2(3b - 2h\gamma)\}\frac{x}{b^3}$$
$$+ \{6W\gamma(3d - b) - 3\epsilon h^2(b - h\gamma)\}\frac{x^2}{b^4}$$

Fig. 1.



where :[1]—

τ denotes the shearing stress on a horizontal plane in any point M of the dam (*Fig. 1*) ;

W ,, vertical weight resting on the horizontal plane drawn through the point M (plane AC on *Fig. 1*) ;

ϵ ,, unit weight of water ;

d ,, distance from the upstream face to the resultant of W ;

x ,, distance from the upstream face to M ;

b ,, width of the dam at AC ;

h ,, depth of water above AC ;

$\gamma = \frac{1}{n}$,, downstream batter, namely, the tangent of the angle between the downstream face and the vertical.

This formula is developed on the assumption that the upstream

[1] The notation used here is slightly different from that in Mr. Hill's Paper.

face is vertical,[1] which is very seldom the case in modern designs (except for the top part of the dam, where the stresses are usually found to be rather low, and are, consequently, less important than near the base). On the other hand, the grapho-analytical method of calculation proposed by the late Professor W. C. Unwin, Past-President Inst. C.E.,[2] applies to any type of profile, and can be, therefore, used for the stress-analysis in gravity dams under all conditions occurring in practice.

Briefly stated, the method is as follows: Let AC and A_1C_1 (*Fig. 2*) be two horizontal planes drawn at a short distance from one another. Further, let—

Δ denote the vertical distance between the two planes;
P ,, weight of masonry in the triangle MOC;
P_1 ,, weight of masonry in the triangle M_1OC_1;
Z ,, force equivalent to the area MJVC;
Z_1 ,, force equivalent to the area $M_1J_1V_1C_1$;
S ,, shearing force on the surface MO;
S_1 ,, shearing force on the surface M_1O;
σ ,, vertical shearing stress at M (which is equal to $-\tau$).

The average shearing stress on the surface MM_1 will be equal[3] to

$$\frac{S - S_1}{\Delta} = \frac{(Z - P) - (Z_1 - P_1)}{\Delta},$$

and therefore

$$\sigma = -\tau = \lim_{\Delta = 0}\left\{\frac{S - S_1}{\Delta}\right\}.$$

Provided Δ is made sufficiently small, this formula can be used for the calculation of the vertical and horizontal shearing stresses. Supposing that S and S_1 are known, the degree of accuracy of the calculation will depend only on Δ, which means that the result can be made as accurate as required.

[1] On the first page of his Paper Mr. Hill states that there is no practical objection to the assumption of verticality, since the depth of the elementary portion of the profile considered in developing the formulas is made zero in the resulting equation. This statement cannot be agreed with, because the equations depend on the batter of both faces of the dam, whatever be the depth of the elementary section.

[2] "Note on the Theory of Unsymmetrical Masonry Dams," *Engineering*, vol. lxxix (1905, Part I), p. 513; "Further Note on the Theory of Unsymmetrical Masonry Dams," *ibid.*, p. 593; "On the Distribution of Shearing Stress in Masonry Dams," *ibid.*, p. 825.

[3] All the formulas are written here on the assumption that the calculations are carried out for a slice of masonry of unit thickness.

If the scale of the stress-diagrams be chosen in such a manner that the area ALVC is equal to the area of the profile above AC,* then

$$S = \text{area COJV}$$

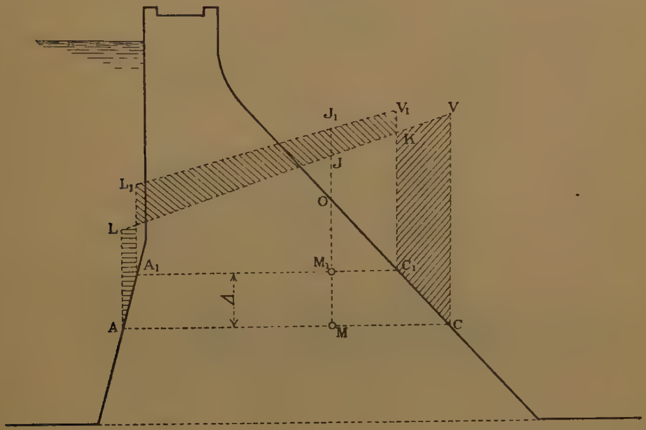
and

$$S_1 = \text{area } C_1OJ_1V_1,$$

so that

$$\sigma = -\tau = \lim_{\Delta = 0}\left\{\frac{\text{area } CC_1KV - \text{area } KJJ_1V_1}{\Delta}\right\}.$$

Fig. 2.



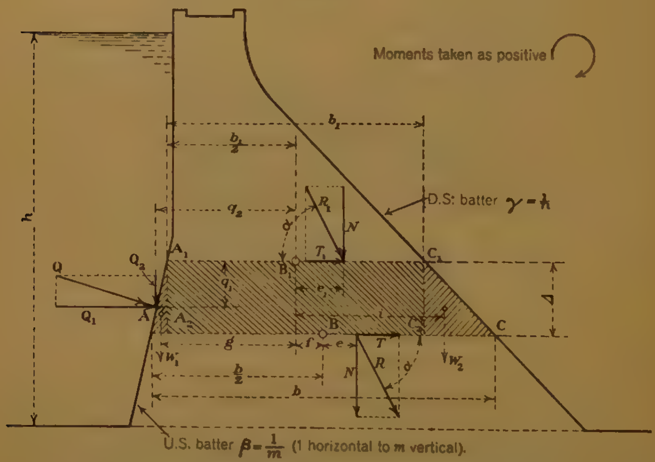
It would, therefore, appear that the shearing stresses in a dam can be determined by measuring on the drawing the areas of the stress-diagrams. This would be an extremely simple operation if it could be done by means of the planimeter. Unfortunately, experience shows that the calculation cannot be carried out in that way. There is no doubt that Professor Unwin's method supplies an elegant solution of the problem, but its application in practice is by no means as simple as it might appear when judged by the simplicity of the equations. The practical difficulties encountered are those inherent in any calculation based on a numerical differentiation, namely, that the percentage error in calculating the difference $S - S_1$ is out of proportion to that allowed in determining S and S_1.

* This involves that the scale used in drawing the stress-diagram should be co-ordinated with that of the profile; thus, if the scale of the profile is taken as $1/w$, then a vertical unit of the stress-diagram must represent wp units of force per unit of area.

The Author's practice with the method tends to show that unless the values of S and S_1 are determined to at least six, or even eight, significant figures, the final result of the calculation is valueless.[1] This prevents the use of either the planimeter or the slide-rule, and makes it impossible to apply any graphical method of computation. To obtain a reasonably accurate result the problem must be solved arithmetically; for instance, as explained below.

With reference to *Fig. 3*, suppose that the components N and T of the resultant R on the plane AC have been already determined in the usual way (either graphically or analytically). Then to find the shearing stresses on the plane AC the vertical component N_1 and the

Fig. 3.



eccentricity e_1 for the plane A_1C_1 are calculated by means of the following formulas :—

$$N_1 = N - Q_2 - F,$$

and

$$e_1 = \frac{N(e+f) - T\Delta - w_2 i + w_1 g + Q_1 q_1 + Q_2 q_2}{N - Q_2 - F},$$

where F denotes the total weight of the block A_1ACC_1. The symbols appearing in these formulas will be made clear from an inspection of *Fig. 3*. It should be emphasized that their values must be determined to a very large number of significant figures, because the final result depends on the differences $N_1 - N$ and $e_1 - e$.

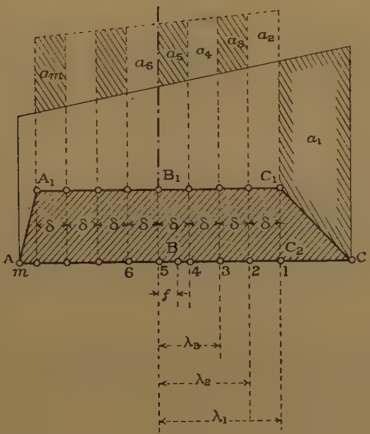
[1] Similar conclusions were arrived at by Mr. William Cain: "Stresses in Masonry Dams," Trans. Am. Soc. C.E., vol. lxiv (1909), p. 208.

Further, in order to plot the diagram of shearing stresses, the length A_1C_1 is divided into a number of equal sections, and the stress at the end of each section is determined from :—

$$\sigma = -\tau = \frac{a_1 - a_2 - \ldots a_m}{\Delta} = \frac{a_1 - \Sigma_2^m a}{\Delta}$$

in which a_1, a_2, a_3 . . ., etc., are equivalent to the areas of the stress-diagrams, as shown on *Fig. 4*. The numerical value of these areas must also be found arithmetically.

Fig. 4.



The calculation can be slightly simplified, as follows. It will be observed that

$$a_2 - a_3 = a_3 - a_4 = \ldots a_{m-1} - a_m = 12\left\{\frac{N_1e_1}{b_1{}^3} - \frac{Ne}{b^3}\right\}\delta^2 = s.$$

Thus, after having calculated a_2 and a_3, all the other areas can be determined from :—

$$a_3 = a_2 - s,$$
$$a_4 = a_3 - s = a_2 - 2s,$$

and generally

$$a_m = a_2 - (m - 2)s.$$

In this form Professor Unwin's solution was given by the Author some time ago in his lectures on Irrigation Design in the Royal School of Engineering, Giza, and proved useful in the class-room as a guide for the students' exercises and general training in stress-computations. The method is, however, very cumbrous and requires

much time and labour. The large number of the successive arithmetical operations which have to be performed, in order to arrive at the final result, obscures the issue and makes it very difficult to grasp the interdependence between the different conditions which are liable to affect the elastic stability of the dam.

The object of the following sections of this Paper is to present a comprehensive general formula and a speedy graphical method, by means of which the intensities of shearing stress on any horizontal plane of the dam can be calculated almost as easily as is the case with the normal stresses.[1]

General Formula for the Calculation of Shearing Stresses.

The general formula for the shearing stresses in dams can be developed from a principle suggested by Professor O. Mohr.[2] Curiously enough, Mohr himself did not give the formula, but used the principle underlying the solution in an arithmetical calculation made by him for one particular profile of a gravity dam. This is, probably, the reason why that solution is not referred to in modern literature, except by some German authors who give it in a form similar to that given by Mohr. So far as the Author can ascertain, the general formula, derived from this solution in the manner described below, has not yet been published.

Professor Mohr's solution is based on the fact that the curve limiting the diagram of shearing stresses for any horizontal plane in a dam is a parabola with a vertical axis, which is represented by the equation

$$\tau = C_1 + C_2x + C_3x^2,$$

where C_1, C_2, and C_3 are three constants[3]. This equation has been

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[1] It is obvious that the proposed method is not intended for the calculation of the maximum shearing stress on inclined planes, which is always equal to half the greatest compression. The suggested solution refers to the same general problem which was dealt with by Mr. Hill and Professor Unwin, namely to obtain exhaustive information on the shearing stresses in all the points of the dam; apart from its first object it is intended to serve in solving several allied problems such as the calculation of the normal stresses on vertical planes, the computation of the ellipses of stresses, etc., and can therefore be considered as forming an integral part of the elastic analysis of a dam-profile.

[2] O. Mohr, "Abhandlungen aus dem Gebiete der technischen Mechanik," second edition, p. 284 *et seq.* Berlin, 1914.

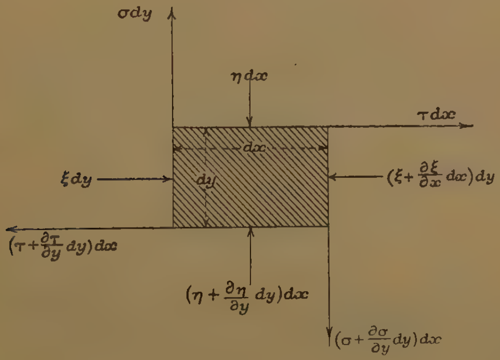
[3] The equation of the parabola with three constants represents the general case. In certain particular cases constants may become zero; if $C_3 = 0$ the diagram becomes a straight line, or if $C_2 = 0$ it becomes a symmetrical parabola.

developed independently by Professor Mohr[1], and earlier by Professor Karl Pearson[2]. It holds good so long as the normal stresses are assumed to vary linearly.

To prove the exactitude of the equation, attention is called to *Fig. 5*. The first condition of equilibrium[3] for the infinitely small prism shown in section on that Figure is found, by resolving vertically, to be :—

$$\frac{\partial \sigma}{\partial x} = \frac{\partial \eta}{\partial y} - \rho.$$

Fig. 5.



Since η is assumed to be a linear function of x, it follows from this formula that $\frac{\partial \sigma}{\partial x}$ must also be such a function, that is, $\frac{\partial \sigma}{\partial x} = D + D_1 x$. Consequently σ must be a quadratic function of x, that is to say, of the form

$$\tau = -\sigma = C_1 + C_2 x + C_3 x^2.$$

Thus, in order to find the distribution of the shearing stresses on a horizontal section of the dam it will suffice to calculate the value of

1 *Loc. cit.*

2 "An Experimental Study of the Stresses in Masonry Dams," London, 1907.

3 Using the same notation and resolving horizontally and by moments, the second and third equations are :—

$$\frac{\partial \tau}{\partial y} = -\frac{\partial \xi}{\partial x} \quad \text{and} \quad \tau = -\sigma,$$

where ξ denotes the normal stress on vertical planes.

the three constants C_1, C_2, and C_3. The particular point of Professor Mohr's solution lies in the manner in which that calculation is performed.

It will be recalled that the horizontal shearing stresses on the upstream and downstream faces of a gravity dam are respectively equal to [1]

$$\tau_u = \{h\epsilon - \eta_u\}\beta$$

and

$$\tau_d = \eta_d\gamma.$$

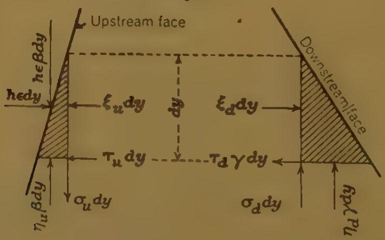
This gives two points on the curve of shearing stresses. On the other part, the area of the curve is, obviously, equal to the total shear, that is $\frac{h^2\epsilon}{2}$, which supplies the third condition required for the calculation of the constants. In Professor Mohr's treatise this calculation is done numerically, by means of the Simpson formula. Instead of that, the three conditions can be used to find the symbolical expression for the constants, as will be shown below.

To simplify the discussion, the equation of the parabola will be written in the form

$$\tau = C_1 + C_4\left(\frac{x}{b}\right) + C_5\left(\frac{x}{b}\right)^2,$$

[1] Suppose that the sketches in *Fig. 6* represent two infinitely small triangular elements on the opposite faces of a gravity dam. Consider first the element on the upstream face. The vertical components of the forces acting on this element are (i) its own weight; (ii) the normal stress $\eta_u\beta dy$ acting on its base; (iii) the vertical component $h\epsilon\beta dy$ of the water-pressure; and (iv) the shearing stress

Fig. 6.



$\sigma_u dy$. As the weight of the element is an infinitely small value of a smaller order than that of the other forces, it follows that, in order to satisfy the condition of equilibrium,

$$\eta_u\beta dy = h\epsilon\beta dy + \sigma_u dy,$$

or

$$\tau_u = -\sigma_u = \{h\epsilon - \eta_u\}\beta$$

Applying the same method to the element on the downstream face,

$$\eta_d\gamma dy = -\sigma_d dy,$$

and

$$\tau_d = -\sigma_d = \eta_d\gamma.$$

in which

$$C_4 = bC_2,$$
$$C_5 = b^2C_3,$$

b denoting the base-width of the dam at the given section, and x being measured from the upstream end of base.

The first condition gives directly the value of the coefficient of C_1, namely

$$C_1 = \tau_u \qquad \ldots \ldots \ldots \quad (1)$$

On the other hand, the second and third conditions can be represented as

$$\tau_d = C_1 + C_4 + C_5 \qquad \ldots \ldots \quad (2)$$

and

$$\int_0^b \tau dx = b\int_0^1 \left\{C_1 + C_4\left(\frac{x}{b}\right) + C_5\left(\frac{x}{b}\right)^2\right\}d\left(\frac{x}{b}\right) = b\tau_m \quad \ldots \quad (3)$$

In the last equation the symbol τ_m is used to denote the average shearing stress $\frac{h^2\epsilon}{2b}$. Integrating this equation,

$$6\tau_m = 6C_1 + 3C_4 + 2C_5 \qquad \ldots \ldots \quad (4)$$

From equations (1), (2), and (4),

$$C_4 = 4(\tau_m - \tau_u) - 2(\tau_d - \tau_m)$$

and

$$-C_5 = 3(\tau_m - \tau_u) - 3(\tau_d - \tau_m).$$

Including these values in the equation of the parabola, it will be found that

$$\tau = \tau_u + \frac{x}{b}[4(\tau_m - \tau_u) - 2(\tau_d - \tau_m)]$$
$$-\left(\frac{x}{b}\right)^2[3(\tau_m - \tau_u) - 3(\tau_d - \tau_m)] \quad \ldots \quad (5)$$

This is the general formula for the calculation of shearing stresses in gravity dams.

Within the limits of the assumptions made—that is to say, in so far as the normal stress is assumed to conform with the rule of the trapezium—the formula is exact and applies to any form of profile. To illustrate the latter point, several typical cross-sections will be examined. As a first instance, the theoretical triangular profile, with the apex on the water-line and the base-width equal to $h\sqrt{\frac{\epsilon}{\rho}}$

(*Figs.* 7), will be considered. The symbol ρ is used here to denote the unit weight of the material of the dam, the ratio $\frac{\epsilon}{\rho}$ being thus the reciprocal of its specific gravity.

As is well known, the normal stresses at the upstream and downstream faces of a dam of that particular profile are respectively equal to

$$\eta_u = 0 \quad \text{and} \quad \eta_d = h\rho\,;$$

hence, since

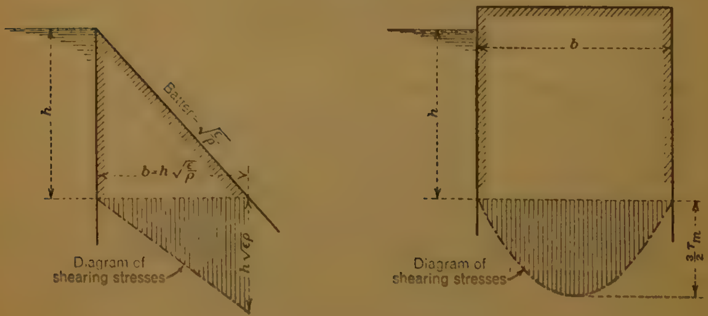
$$\beta = 0 \quad \text{and} \quad \gamma = \sqrt{\frac{\epsilon}{\rho}}$$

$$\tau_u = h\epsilon\beta = 0$$

and

$$\tau_d = \eta_d\gamma = h\sqrt{\epsilon\rho}.$$

Figs. 7.



Further, since $\tau_m = \frac{h\sqrt{\epsilon\rho}}{2}$, it follows that

$$C_1 = 0,$$
$$C_4 = h\sqrt{\epsilon\rho} = 2\tau_m,$$
$$C_5 = 0.$$

Consequently, the equation of shearing stresses is

$$\tau = 2\tau_m\frac{x}{b}.$$

This formula represents a straight line, as shown in *Figs.* 7. The

result agrees with the conclusions arrived at independently and in a different manner by Maurice Lévy,[1] Professor Unwin,[2] and Professor Mohr.[3]

As another instance, considering a rectangular wall, with both faces vertical (*Figs. 7*),

$$\gamma = \beta = 0,$$

and therefore

$$\tau_u = \tau_d = 0.$$

It follows that $C_1 = 0$ and $C_4 = -C_5 = 6\tau_m$, which gives

$$\tau = \left[\frac{x}{b} - \frac{x^2}{b^2}\right] 6\tau_m.$$

This equation defines a symmetrical parabola with a vertical axis passing through the middle point of the base b. As might have been expected, the shearing-stress distribution is exactly the same as in an ordinary beam with a rectangular cross-section.

The two instances considered might be taken to represent, in a certain sense, the extreme limiting conditions for the possible shape of any shearing-stress diagram, because the triangle and the parabola (which were found to give the shearing-stress distribution in these cases) are the elementary forms usually found to be combined with each other when the stress-calculation refers to a practical profile.

Such a profile will now be considered as a third example, in order to show how the general formula can be used in practical dam-designing. The particular profile selected (*Fig. 8*, p. 88) is that which is given as an example by Messrs. P. Lévy-Salvador and M. F. Bonnet.[4] The normal stresses for that profile—calculated by Mr. Lévy-Salvador under two assumptions as regards the water-level in the reservoir—will be found in the upper parts of Tables I and II (pp. 88–89), which contain also various other information usually given in such Tables. On the other hand, the lower parts of the Tables are intended to explain the consecutive stages of the calculation of shearing stresses according to the " general formula." The order of

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[1] Comptes Rendus de l'Académie des Sciences, vol. 121 (1895, Part 2), p. 288; vol. 126 (1898, Part 1), p. 1235; vol. 127 (1898, Part 2), p. 10.

[2] *Engineering*, vol. lxxix (1905, Part I), p. 593.

[3] " Abhandlungen aus dem Gebiete der technischen Mechanik," second edition, p. 294.

[4] M. F. Bonnet, " Cours de Barrages," Paris, 1920; P. Lévy-Salvador, " Utilisation des Chutes d'Eau, en vue de la production de l'energie électrique."

Fig. 8.

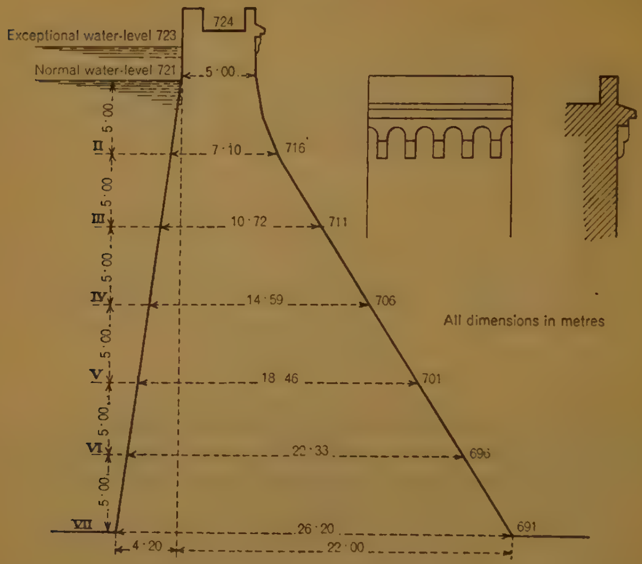


TABLE I.—NORMAL WATER-LEVEL IN RESERVOIR, R.L. 721·00.

(All stresses in tonnes per square metre.)

1	Section		2	3	4	5	6	7
2	Level above datum .		716	711	706	701	696	691
3	Width of dam b . .		7·10	10·72	14·59	18·46	22·33	26·20
4	Water depth h . .		5	10	15	20	25	30
5	Normal stress, up-stream face, $= \eta_u$.		18·0	23·4	26·5	29·2	31·6	33·7
6	Normal stress, down-stream face, $= \eta_d$.		12·0	15·6	22·5	30·6	39·4	48·7
7	Average shearing stress, $= \tau_m = h^2\epsilon/2b$ . .		1·76	4·66	7·71	10·83	14·00	18·18
8	Shearing stress, up-stream face, $\tau_u = (h\epsilon - \eta_u)\beta$.		—1·72	—1·93	—1·66	—1·32	—0·95	—0·53
9	Shearing stress, down-stream face, $\tau_d = \eta_d\gamma$		5·88	9·59	14·18	19·28	24·82	30·68
10	$\tau_m - \tau_u = a$		3·48	6·59	9·37	12·15	14·95	17·73
11	$\tau_d - \tau_m = b$ . . .		4·12	4·93	6·47	8·45	10·82	13·50
12	$K_1 = 4a - 2b$ . . .		5·68	16·50	24·54	31·70	38·16	43·92
13	$K_2 = 3a - 3b$ . . .		—1·92	4·98	8·70	11·10	12·39	12·69
14	Shearing stresses	$n=1$	—0·72	0·70	2·19	3·64	5·07	6·44
15	$\tau = \tau_u + K_1\frac{n}{6} - K_2\left(\frac{n}{6}\right)^2$,	$n=2$	0·39	3·02	5·54	8·02	10·58	12·70
16	where n is a whole	$n=3$	1·60	5·07	8·43	11·75	15·03	18·26
17	number ranging from	$n=4$	2·92	6·85	10·74	15·01	18·95	23·06
18	1 to 5.	$n=5$	4·35	8·36	12·71	17·40	22·23	27·26

the calculation is as follows : first find the average and the upstream and downstream shearing stresses, and then calculate

$K_1 = 4(\tau_m - \tau_u) - 2(\tau_d - \tau_m)$ and $K_2 = 3(\tau_m - \tau_u) - 3(\tau_d - \tau_m)$.

This part of the calculation is shown in lines 7 to 13 of the Tables. The last operation consists in finding the stress at a number of points in a horizontal plane AC across the dam, and for this purpose the width b is divided into 6 sections, the number 6 being chosen arbi-

TABLE II.—EXCEPTIONAL WATER-LEVEL IN RESERVOIR, R.L. 723·00.

(All stresses in tonnes per square metre.)

1	Section		2	3	4	5	6	7
2	Level above datum .		716	711	706	701	696	691
3	Width of dam b . .		7·10	10·72	14·59	18·46	22·33	26·20
4	Water depth h . .		7	12	17	22	27	32
5	Normal stress, upstream face, $= \eta_u$.		14·3	18·6	20·6	22·5	24·7	26·5
6	Normal stress, downstream face, $= \eta_d$.		15·9	21·6	29·0	37·9	46·9	56·5
7	Average shearing stress, $= \tau_m = h^2\epsilon/2b$ . .		3·45	6·70	9·90	13·1	16·3	19·5
8	Shearing stress, upstream face, $= \tau_u = (h\epsilon - \eta_u)\beta$.		—0·96	—0·95	—0·52	—0·07	0·33	0·79
9	Shearing stress, downsteam face, $\tau_d = \eta_d\gamma$		7·79	13·3	18·3	23·8	29·5	35·6
10	$\tau_m - \tau_u = a$ . . .		4·41	7·67	10·42	13·19	15·99	18·75
11	$\tau_d - \tau_m = b$ . . .		4·34	6·56	8·37	10·69	13·16	16·06
12	$K_1 = 4a - 2b$ . . .		8·96	17·56	29·94	31·38	37·64	42·88
13	$K_2 = 3a - 3b$ . . .		0·21	3·33	6·15	7·50	8·49	8·07
14	Shearing stresses $\tau = \tau_u + K_1\frac{n}{6} - K_2\left(\frac{n}{6}\right)^2$, where n is a whole number ranging from 1 to 5.	$n=1$	0·53	1·89	3·46	4·95	6·37	7·72
15		$n=2$	2·01	4·57	7·09	9·56	11·94	14·10
16		$n=3$	3·47	7·00	10·41	13·74	17·03	20·21
17		$n=4$	4·92	9·27	13·40	17·50	21·68	25·78
18		$n=5$	6·36	11·39	16·02	20·90	25·92	30·95

trarily as giving a suitable number of points for the computation of a comprehensive graph. Instead of $\frac{x}{b}$ its equivalent $\frac{n}{6}$ can now be substituted, giving for the general formula

$$\tau = \tau_u + K_1\frac{n}{6} + K_2\left(\frac{n}{6}\right)^2,$$

where n is a whole number varying from 1 to 5.

The results of the calculation are shown in the lower part of the Tables; they are also represented graphically on Figs. 15 and 18, Plate 1. For the sake of comparison the normal stresses are reproduced on Figs. 14 and 17, Plate 1.

In considering Table I and Fig. 14, Plate 1, it will be observed that the normal stresses on the upstream face of the dam are all greater than the intensities of water-pressures in the reservoir at the same levels. This condition is often referred to on the Continent as the "rule of Maurice Lévy." It was first proposed in Mr. Lévy's communication[1] to the French Academy of Sciences dated the 5th August, 1895, the intention being to ensure safety against the dangerous action of uplift (it was supposed that water could not infiltrate into the body of a dam so long as the stress in the masonry was greater than the water-pressure). Though it involved a larger amount of material than the usual "middle third rule," Mr. Levy's criterion was often used in France in the period following the failure of the Bouzey dam (on the 24th April, 1895), which caused much loss of life and terrorized a whole generation of French dam designers. This explains why the French barrages of the first quarter of this century were sometimes wider in section than was usual in the same period in other countries.

As the reservoir-level rises the water-pressure increases while the normal stress on the upstream face of the dam falls, the result being that in the case referred to in Table II and in Figs. 17 and 18, Plate 1 (exceptionally high water-level) the stresses in the lower part of the dam do not conform to the rule of Maurice Lévy. The outline of the shearing-stress diagrams is to a certain extent dependent on whether the normal stresses are in accordance with that rule, or not; in all the cases when the rule is adhered to (as with all sections on Fig. 15, Plate 1, and the upper four sections on Fig. 18, Plate 1), the shearing stresses are found to change in sign, being negative on the upstream face, whilst in the remaining two sections on Fig. 18, Plate 1, they are of the same sign throughout all the width of the dam. This curious relationship would no doubt have been a matter of interest and surprise to Mr. Lévy.

New Graphical Method for the Computation of Shearing Stresses.

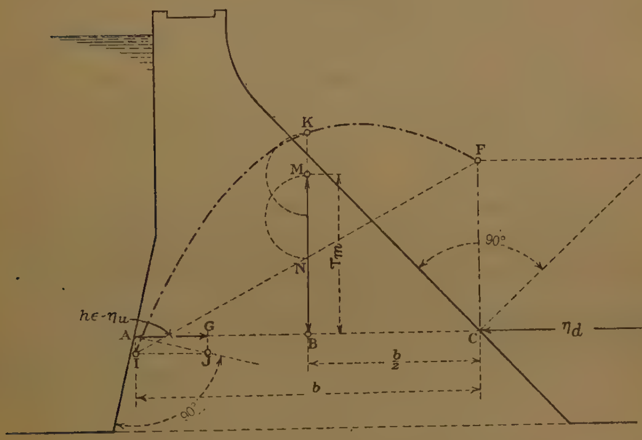
About an hour would suffice to carry out all the calculations which are shown in Tables I and II, all of which can be done by means of the ordinary slide-rule. Thus, as compared with Professor Unwin's method, the proposed general formula for the calculation of shearing stresses is far easier to employ. Also, the general formula possesses the double advantage over Mr. E. P. Hill's equation of being true for

[1] *Loc. cit.*

any type of profile and of being much handier in use. There is, however, another method which is still simpler and more comprehensive. This is the graphical computation described below.

The only value which has to be calculated arithmetically is the average shearing stress $\frac{h^2\epsilon}{2b} = \tau_m$, whilst all the other factors determining the shearing stresses, as well as these stresses themselves, can be obtained graphically, as follows. A convenient scale is selected and the values of η_d and $h\epsilon - \eta_u$ are plotted on the drawing as shown on *Fig. 9*; the line CE is then drawn at right angles to the downstream face of the dam, and the point E found where this line meets

Fig. 9.



the vertical line DE; then, the horizontal line EF drawn through E will fix the vertical length FC, which is equivalent to the downstream shearing stress τ_d. The upstream shearing stress τ_u, represented on the drawing by the length AI, is found in the same way, by means of the three straight lines GJ, AI, and JI, which fix the position of the points J and I.

When this has been done, a line is traced through F and I, and the stress τ_m is plotted vertically upwards from the point B (middle point of width b), making MB $= \tau_m$. This defines the length MN; MK is then plotted upwards from M and made equal to $\frac{\text{MN}}{2}$, so that NK $= \frac{3\text{MN}}{2}$. A parabola, drawn through the points I, K, and F,

in the usual way, will exactly represent the curve of shearing stresses,[1] as can easily be proved.

In drawing *Fig. 9* it was tacitly assumed that $h\epsilon$ is less than η_u (the rule of Maurice Lévy), and therefore $h\epsilon - \eta_u$ was plotted inwards from the line representing the upstream face of the dam. Should it be found that $h\epsilon - \eta_u$ is positive, its value must be plotted in the opposite direction, namely, as shown on *Fig. 11* and on the two lower sections on Fig. 19, Plate 1.

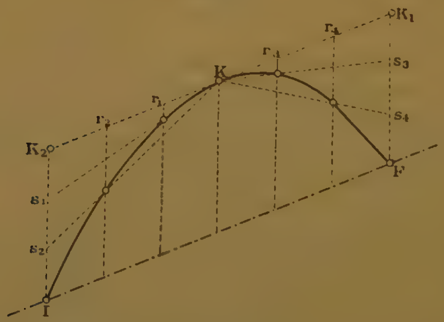
It may also occur (though not very often) that the upper end of the line representing the average stress τ, when plotted in the manner described, will fall below the straight line joining the points I and F. This case is represented diagrammatically in *Fig. 12.* The length MN will then be divided into two, as was done in the previous cases, but, instead of being located above the line IF, the point K will be found by plotting $\text{MK} = \frac{\text{MN}}{2}$ downwards from the point M. In this case the parabola, instead of being concave downwards, will be convex, but in all other respects the computation will be exactly the same as before.

Conditions when the Reservoir is Empty.

In looking through some of the books relating to dam design, a reader might be led to think— though no statement to that effect is

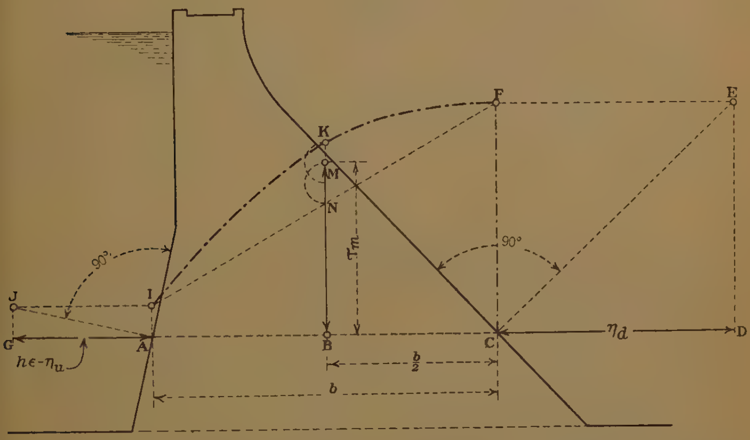
[1] The simplest method for obtaining this parabola is as follows: trace through K (*Fig. 10*) a parallel to IF; it intersects the verticals drawn through I and F in the points K_1 and K_2; divide K_2K and K_2I into the same number of equal parts (for instance three), draw verticals through r_1 and r_2 and join K with s_1 and s_2. The points where these lines intersect define the required parabola. The computation for the right-hand side will be exactly the same as for the left.

Fig. 10.



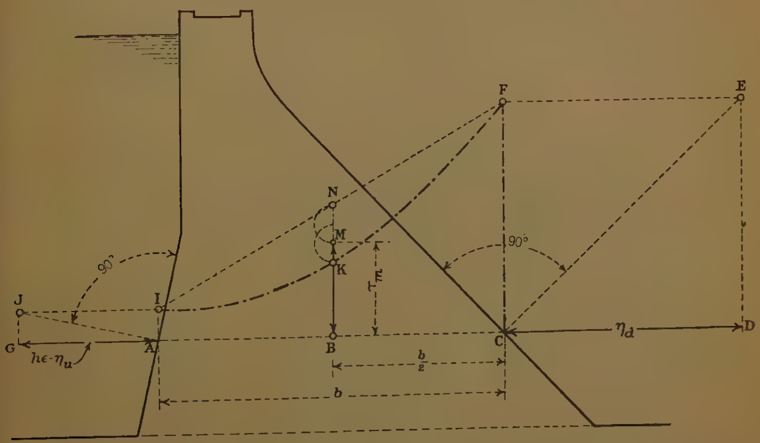
made explicitly—that shearing stresses occur only when there is an external shearing force, that is to say, when there is water in the

Fig. 11.



reservoir. This conclusion is altogether false. Whether there is an external shearing force or not, shearing stresses are found to exist in almost all the structures which an engineer has to design, and

Fig. 12.



under nearly all the conditions which he has to assume for the calculation of stresses. However, there are many cases when the sum of all the shearing stresses falling in an imaginary section drawn

through the structure (or an element of the structure) is zero. This is precisely the case of a dam when the reservoir is empty.

Referring again to the proposed general formula for shearing stresses, it will be found that in this case, τ_m being equal to zero, the equation becomes

$$\tau = \tau_u - \frac{x}{b}\left[4\tau_u + 2\tau_d\right] + 3\left(\frac{x}{b}\right)^2\left[\tau_u + \tau_d\right].$$

This equation has been used in preparing Table III, which shows

TABLE III.—RESERVOIR EMPTY.

(All stresses in tonnes per square metre.)

1	Section		2	3	4	5	6	7
2	Level above datum .		716	711	706	701	696	691
3	Width of dam b . .		7·10	10·72	14·59	18·46	22·33	26·20
4	Normal stress, upstream face, η_u . .		20·5	30·7	40·0	48·9	57·9	66·9
5	Normal stress, downstream face, η_d . .		10·3	8·9	9·0	10·3	12·1	14·1
6	Shearing stress, upstream face, $\tau_u = -\eta_u\beta$ . . .		—2·71	—4·42	—5·76	—7·04	—8·34	—9·63
7	Shearing stress, downstream face, $\tau_d = \eta_d\gamma$		5·05	5·47	5·67	6·49	7·62	8·88
8	$K_1 = 4\tau_u + 2\tau_d$ . .		—0·74	—6·74	—11·70	—15·18	—18·12	—20·76
9	$K_2 = 3(\tau_u + \tau_d)$ . .		7·02	3·15	—0·27	—1·65	—2·16	—2·25
10	Shearing stresses $\tau = \tau_u - K_1\frac{n}{6} + K_2\left(\frac{n}{6}\right)^2$, where n is a whole number varying from 1 to 6.	$n=1$	—2·39	—3·21	—3·82	—4·57	—5·38	—6·23
11		$n=2$	—1·68	—1·83	—1·87	—2·18	—2·54	—2·92
12		$n=3$	—0·58	—0·26	0·02	0·12	0·18	0·19
13		$n=4$	0·91	1·40	1·91	2·45	2·78	3·19
14		$n=5$	2·78	3·38	3·79	4·45	5·26	6·09

the consecutive steps of the computation carried out for the same profile as the first two Tables, but for the case of an empty reservoir. The shearing stresses calculated in this Table are represented in Fig. 21, Plate 1, whilst in Fig. 22, Plate 1, the same stresses are shown as determined graphically.

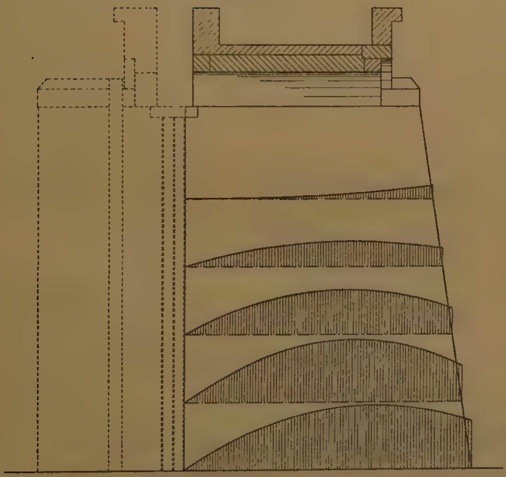
APPLICATION OF THE GENERAL FORMULA TO OTHER STRUCTURES.

The field of application of the general formula for shearing stresses is by no means confined to the design of dams, but includes also various other works such as barrages, weirs, and regulators. As an example, the case of a pier in a barrage will be considered.

Apart from the structural weight and the rolling loads, such a pier is subject to the effect of the hydraulic pressure, part of which is applied directly and part transferred through the gates. Neglecting, because of its smallness, the water-pressure on the downstream face of the pier, and assuming, as is commonly done, that a vertical crack in line with the bearing surfaces of the grooves separates the masonry into two parts, the horizontal shearing stresses for the downstream part (which is supposed to take all the horizontal loads) are found to be as follows:—

$$\tau_u = 0,$$
$$\tau_d = \eta_d \gamma,$$
$$\tau_m = \frac{S}{bw}.$$

Fig. 13.



In these formulas the notation for the upstream and downstream stresses is the same as before, while in the third equation, which gives the value of the average stress, S denotes the total shearing force above the plane considered and w denotes the width of the pier.

If s denotes the clear span in between the piers, then

$$S = \frac{h^2 \epsilon}{2}(s + w).$$

In all other respects the calculation of shearing stresses is done in

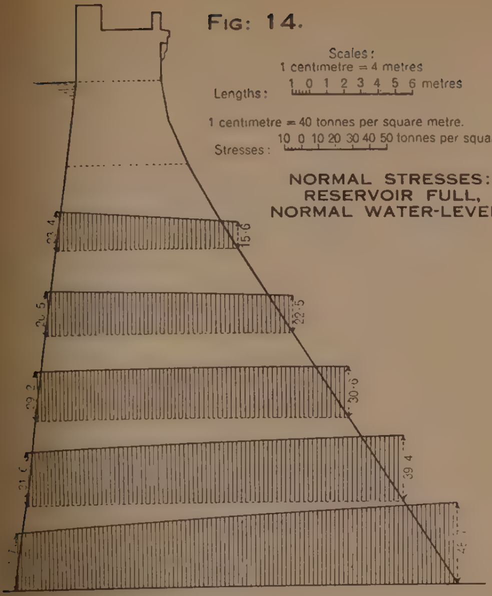
the same way as before, and, since $\tau_u = 0$, the general formula becomes

$$\tau = \frac{x}{b}\left(6\tau_m - 2\tau_d\right) - \left(\frac{x}{b}\right)^2\left[6\tau_m - 3\tau_d\right].$$

The results of the calculation carried out according to this formula for the piers of the Assiut barrage (before its strengthening) are shown in *Fig. 13*. It will be observed that in this case the diagrams bear an obvious resemblance to those obtained for an ordinary beam when subject to bending.

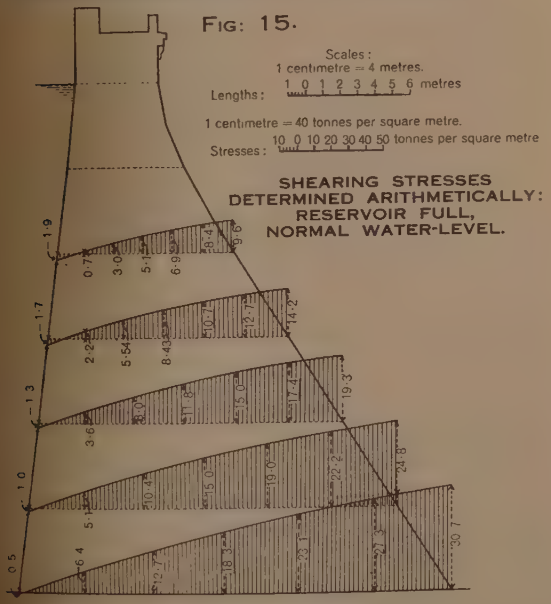
The Paper is accompanied by twenty-four drawings, from which Plate 1 and the Figures in the text have been prepared.

FIG: 14.



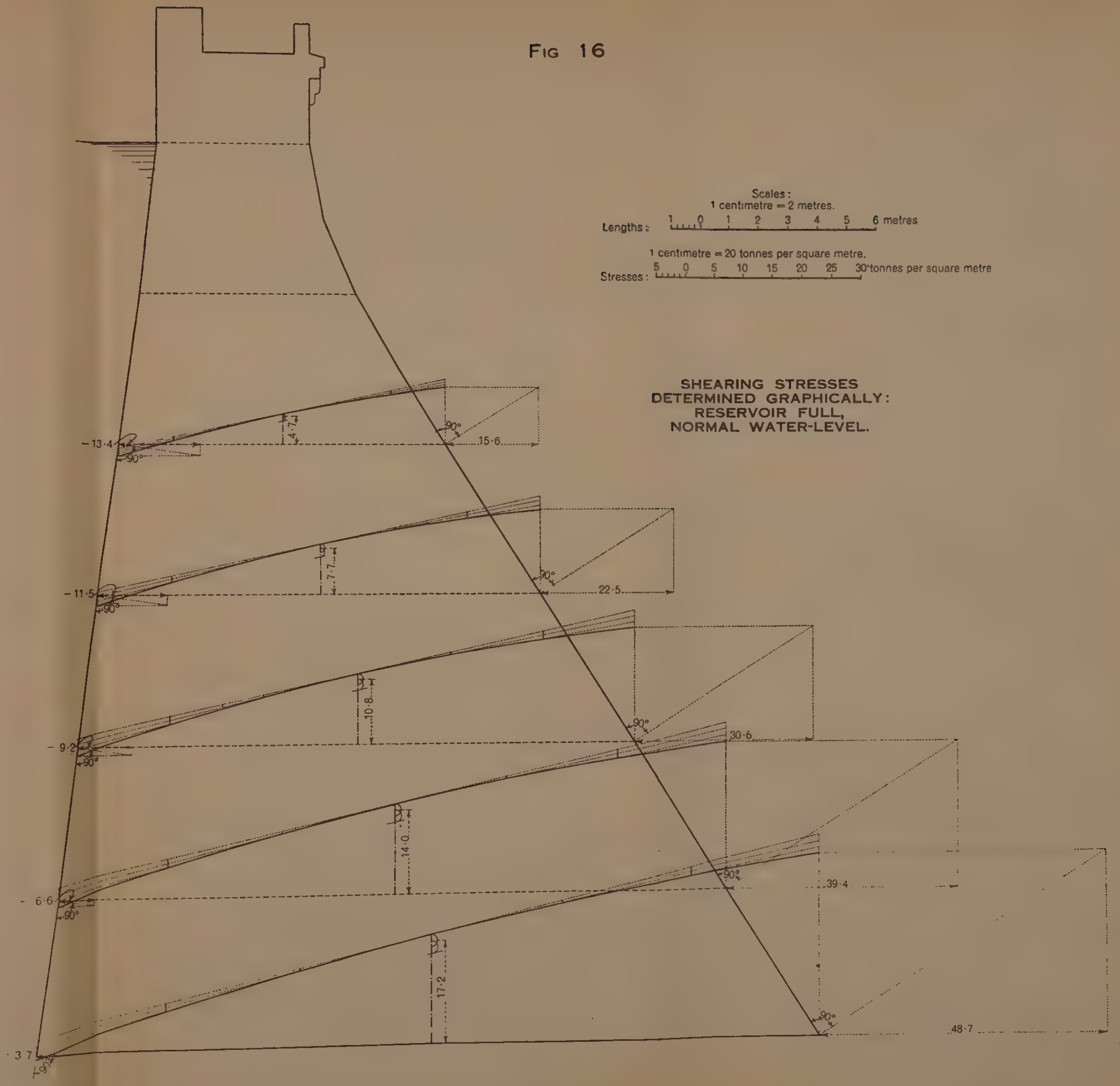
NORMAL STRESSES:
RESERVOIR FULL,
NORMAL WATER-LEVEL.

FIG: 15.



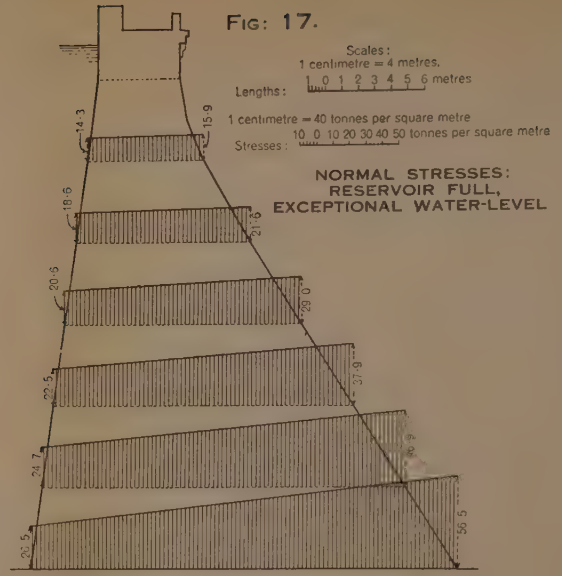
SHEARING STRESSES
DETERMINED ARITHMETICALLY:
RESERVOIR FULL,
NORMAL WATER-LEVEL.

FIG 16



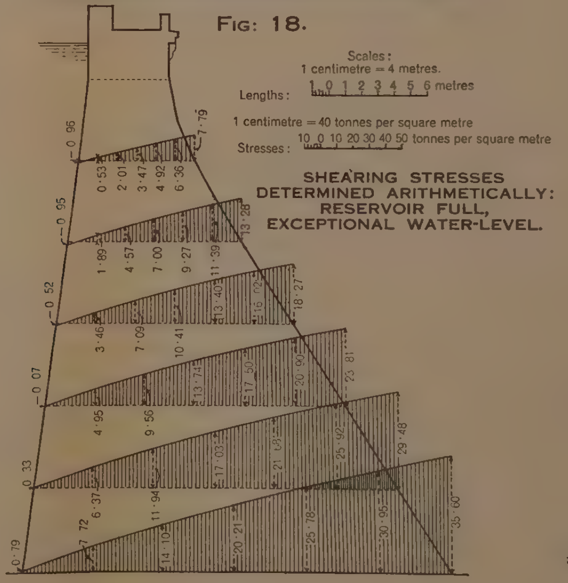
SHEARING STRESSES
DETERMINED GRAPHICALLY:
RESERVOIR FULL,
NORMAL WATER-LEVEL.

FIG: 17.



NORMAL STRESSES:
RESERVOIR FULL,
EXCEPTIONAL WATER-LEVEL

FIG: 18.



SHEARING STRESSES
DETERMINED ARITHMETICALLY:
RESERVOIR FULL,
EXCEPTIONAL WATER-LEVEL.

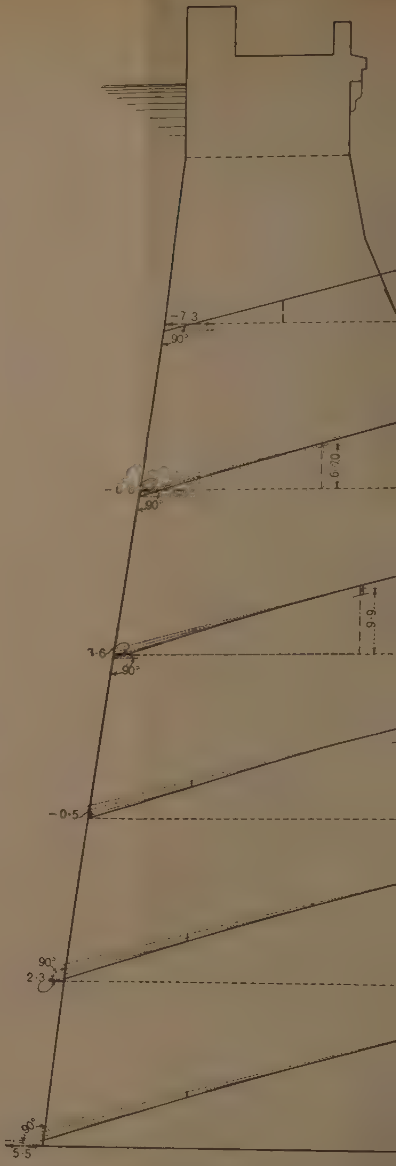


FIG: 19.

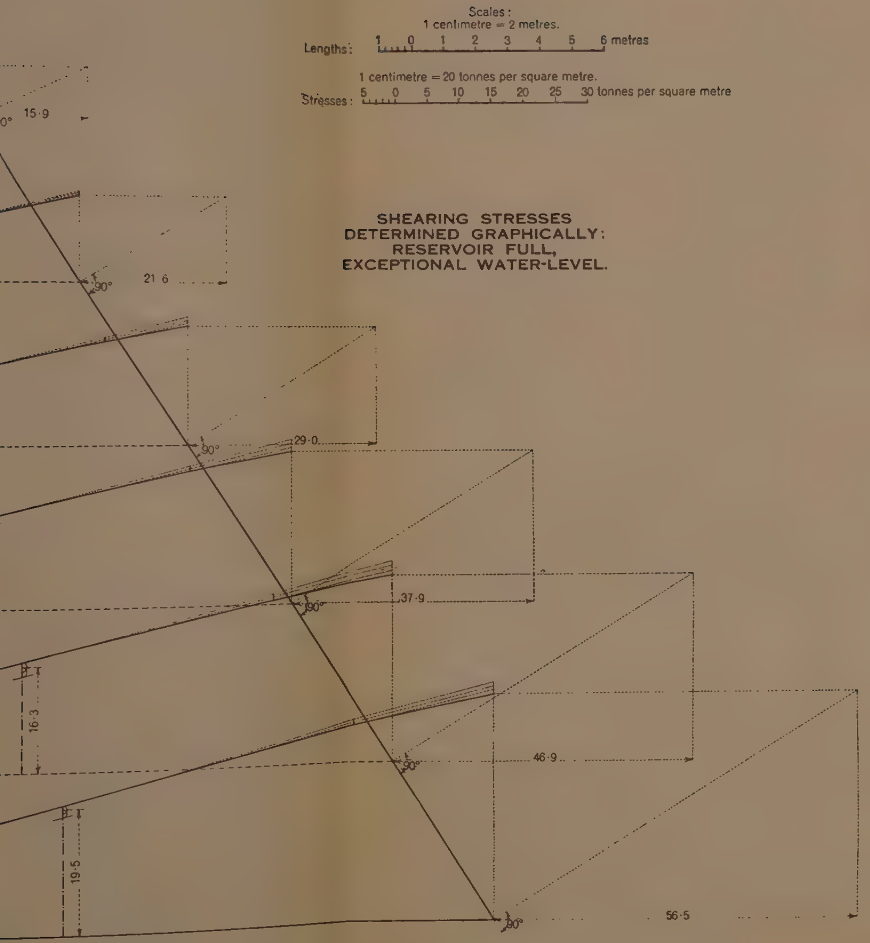


FIG: 20.

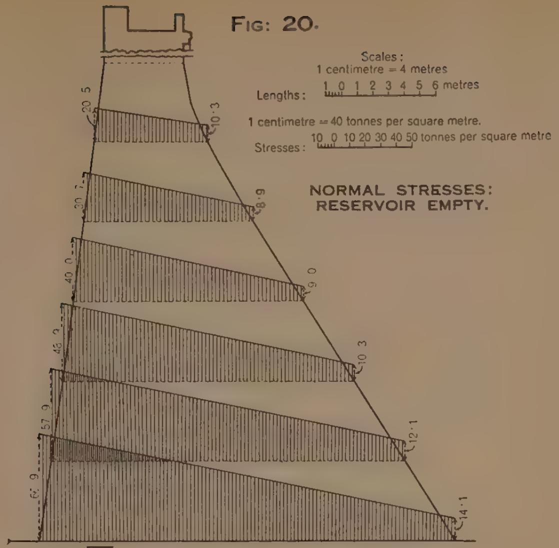


FIG: 21.

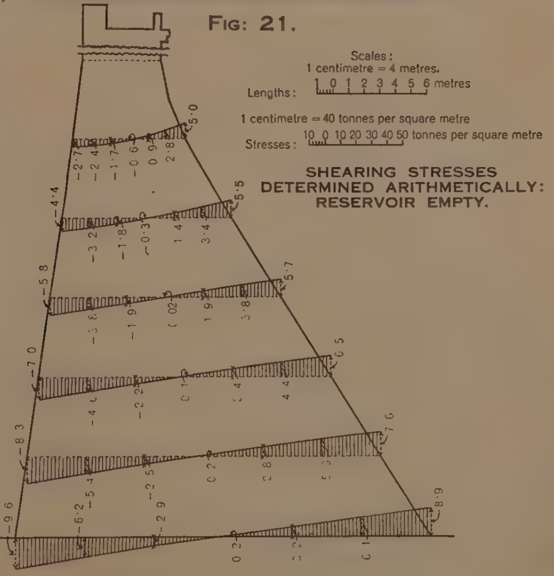
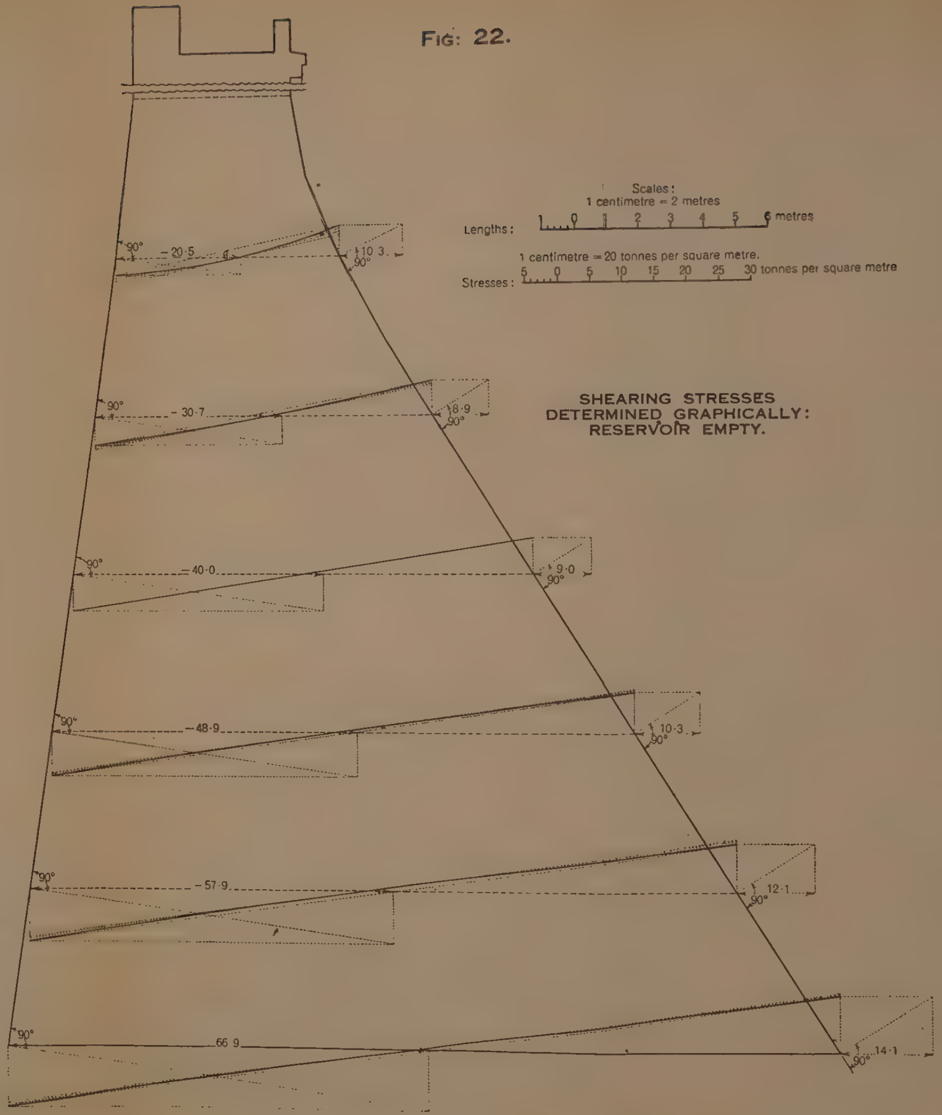


FIG: 22.



SERGE LELIAVSKY.

ENGINEERING RESEARCH.

FINAL REPORT OF THE DEPARTMENTAL COMMITTEE ON NOISE IN THE OPERATION OF MECHANICALLY PROPELLED VEHICLES.[1]

The First, Second, and Third Interim Reports were published in 1935, 1936, and 1937. These surveyed and made recommendations in respect of the noise produced by new vehicles generally, by particular types, and by used vehicles respectively.

The Final Report which has recently been issued deals with the problem of the noise of warning devices used on motor vehicles. The degree of annoyance caused by a warning sound is dependent upon quality as well as loudness. Thus high-pitched horns are in general more objectionable than low-pitched ones of the same loudness, and the more musical types of sound less objectionable than the harsh types. Nevertheless the overall loudness has a high significance and has the advantage of being an easily measurable quantity. From the point of view of residents and quiet road users in relatively quiet streets, horns exceeding 95–100 phons (B.S.) at a distance of 20 feet cause a material degree of annoyance. In relation to such conditions, it appears that many present-day motor horns are excessively loud.

From the point of view of a driver subjected to the noise of his vehicle and about to be overtaken by another vehicle, it is necessary to permit a loudness of the order 105 phons (B.S.), as measured at a distance 20 feet in front of the horn in the open, in order to ensure that all types of horns can give adequate warning where the level of the vehicle-noise is moderate, such as in the case of private cars and the lighter types of commercial vehicles. Where the level of the interior noise is excessive, very powerful horns of loudness 110 phons (B.S.) or more are required to give adequate warning.

A compromise between these conflicting requirements has been made in the recommendations where a maximum loudness of 100 phons (B.S.) at a distance of 20 feet in front and to each side is advocated, except for fire-engines, ambulances and the like.

[1] Published by H.M. Stationery Office, 1*s*. 3*d*.

RESEARCH IN ENGINEERING AT NORTHAMPTON POLYTECHNIC.

Research in Engineering is being carried out in the Departments of Civil and Mechanical and of Electrical Engineering, chiefly in connexion with the evening courses in Engineering.

Civil and Mechanical Engineering.

An investigation is being made of the distribution of stress and deformation in riveted joints. The behaviour of single rivets is being studied in the first place, and it is hoped later to extend the research to a study of the distribution of stress with two or more rivets.

The embrittlement of certain steels due to prolonged exposure to high temperatures is being investigated. This type of embrittlement is peculiar in that the standard tensile test results are practically identical with those obtained from un-heated tough specimens, and so give little indication that a low Izod value is to be expected. A more detailed study of the tensile test may reveal a difference between the two cases.

A new method of analysis for trials on engineering plant is being developed. The method applies the principle of the conservation of energy to plant enclosed within an imaginary boundary, and obviates the possibility of erroneous items appearing in heat-balance sheets. An application of the method to engine trials has already exposed an error which is being perpetuated in official reports and also in text-books, namely, that of including friction horse-power, or its heat equivalent, as a separate item on heat-balance sheets.

A study is being made of the scavenging of water-cooled two-stroke motor-cycle engines. The effect of alterations in the shapes of piston and piston head, compression-ratio, etc., on the completeness of combustion and thermal efficiency is being studied.

A study is being made of the theory and performance of ring-flow meters used for the measurement of pressure-differences in hydraulic metering devices.

Electrical Engineering.

An investigation is being made of magnetic performance under combined A.C. and D.C. excitation. Work is in hand upon transformer and choke-core assemblies, with special reference to effects introduced by the magnetic joints and by magnetic leakage. This investigation relates to a wide range of core sizes and of core materials.

A research on the behaviour of strip samples under combined A.C. and D.C. excitation aims at establishing a permeameter method of estimating, under actual excitation conditions, the incremental permeability and losses of magnetic sheet material, such as would be used in the construction of communications, transformers and chokes intended for operation under polarized conditions.

A simulated ballistic test equivalent to combined A.C. and D.C. excitation is being evolved to deal with ring samples and transformer-core assemblies. This research was undertaken because all specified permeability-measurements are at present based on the ballistic test. None of these, however, refers to the special case of incremental magnetization which provides particular problems in measurement, and it is hoped to decide from the tests whether a ballistic measurement is suitable in this class of magnetization or not.

A precision measuring-device is being developed capable of accurate determinations of incremental permeability and losses over a wide frequency-range. Precision apparatus for this measurement is, at present, very complicated and, in general, suitable only for low-frequency superimposed A.C. It is desired, therefore, to develop simple apparatus of comparable accuracy and capable of application at both power- and audio-frequencies.

An investigation into the measurement of phase at audio-frequency, which is nearly completed, aims at providing a means of accurate estimation of phase-difference up to the highest audio-frequencies.

A study is being made of the performance and design of fractional-horse-power motors. Many applications exist in the electrical industry for the miniature high-speed motor, but there are a number of problems concerned with the estimation of its performance and particularly with the details of its design.

An investigation is projected into arc-rupturing in the smaller types of circuit-breakers, contactors and fuses under A.C. conditions, and the preliminary lay-out and construction of apparatus is in hand.

Researches in the preliminary stage include a research into dielectric properties of insulating materials under superimposed A.C. and D.C. pressure, a study of the properties of magnetic dust-core coils, and work on A.C. and D.C. metering problems in circuits containing dry metal rectifiers.

The above researches are being carried out under the direction of Mr. J. G. Docherty, D.Sc., Head of the Department of Civil and Mechanical Engineering, Mr. L. G. A. Sims, Ph.D., D.Sc., Head of the Department of Electrical Engineering, and members of the staffs of these Departments.

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* An exact solution of the problem of the short wave, *Ann. P. et C.*, **107** (*ii*) *392.*

* Flow over masonry weirs and notches, *Inst. Eng. India*, **17,** *201.*

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Some apparatus for specialized use on sites of new foundations, *Structural Engineer*, **16,** *14.*

The figure in heavy type is the number of the Volume; that in brackets the number of the Part; and that in italic type the number of the Page. In references to "Engineering Abstracts" the number of the Volume is given in heavy type, the section is indicated by the abbreviation Con., Mech., Ship., or Min., and the number of the Abstract is printed in italic type. The scheme of tabulation is given in the January, 1938, Journal (pp. 475–477), to which reference should be made.

* When it is known that a reference will appear in an early issue of "Engineering Abstracts" this fact is indicated by an asterisk.

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* Checking the design of a rigid-frame bridge by field tests, *Rly. Age*, **103**, *788*.

* Tests on tee-beams with high elastic limit reinforcement, *Deu. Ausschuss Eisenbeton, Heft 86*.

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[1] See p. 97, *ante*.

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Synthetic moulding sand, *Giesserei*, **25,** *622*.

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(3) *Explosives.*

The shock-wave and explosion products from detonating solid explosives, *Prov. Roy. Soc. A*, **163,** *575* (Abs. **1,** Min. *9*).
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(10) *Electricity as applied to Mining.*

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(1) *Generation, Distribution, Machines, etc.*

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(1) *Aeronautical.*

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